Study of Harnessing Raindrop Energy Potential in Perak, Malaysia

by

Noor Farhane Binti Che Harun

Dissertation submitted in partial fulfillment of

the requirements for the

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(Mechanical Engineering)

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Universiti Teknologi PETRONAS,
Bandar Seri Iskandar,
31750 Tronoh,
Perak Darul Ridzuan.

CERTIFICATION OF APPROVAL

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Approved by,

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(Ir Idris Ibrahim)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

May 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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NOOR FARHANE BINTI CHE HARUN

ABSTRACT

The main objective of this project is to determine the potential electrical power that can be generated from raindrop impact on piezoelectric material. Previous studies show that the fossil fuel production is depleting and with the rapid growth of population, the remainder supply could not keep up with the energy demand. Therefore, new alternative energy is required to avoid full dependency on fossil fuel. This is a preliminary study focus on rainfall records of Perak, Malaysia to obtain the significant of this new source of energy. By referring to previous study and finite element method, the mathematical model in developed and simulate to define the vibratory movement, strain and potential energy exerted from raindrop impact on polyvinylidene fluoride. The finding shows that the energy output from100m^2 PVDF plate area was very low in the range of 0.49mJ .The detail of this project are discussed in this paper.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Malaysia located between the equator (0°) and the northern 7° latitude experience a predominantly equatorial climate [1]. The characteristic features of the climate of Malaysia are uniform temperature, high humidity and abundant rainfall. Winds are generally light. Situated in the equatorial area, it is extremely rare to have a full day with completely clear sky even during periods of severe drought. On the other hand, it is also rare to have a stretch of a few days with completely no sunshine except during the northeast monsoon seasons. Surrounded by maritime, Malaysia's weather influenced by two monsoon regimes; Southwest from Hindi Sea and Northeast Monsoon from South Chinese Sea. The Northeast Monsoon brings heavy rainfall, particularly to the east coast of Peninsular Malaysia and western Sarawak, whereas the Southwest Monsoon affecting west coast of Peninsular Malaysia [2].

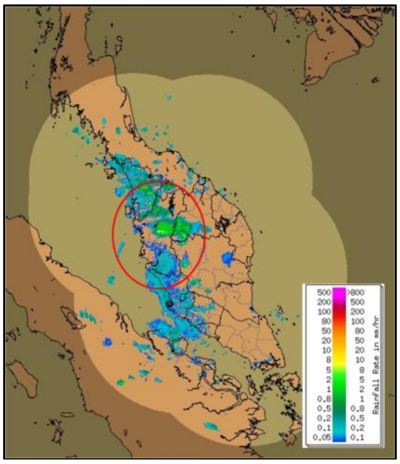

Figure 1.1: Daily Rainfall Distribution of Peninsular Malaysia from Malaysia Meteorology Department website

Figure 1.1 is topography map of daily rainfall distribution of Peninsular Malaysia published by Malaysia Meteorology Department, it shows that Perak received higher amount of rainfall compare to other states in Malaysia. Therefore, it is right decision of choosing Perak as case study. Beside, Figure 1.2 shows the frequency of day of rainfall occurs per month. There, shows that rainfall is frequent occur in Perak which bring high amount of rain enough since the minimum rainfall amount is not less than 1300 millimeters while the maximum exceed 3500 millimeters per annum. Therefore, Perak have high potential to as a starter for establishing this type energy concept after this project found significant.

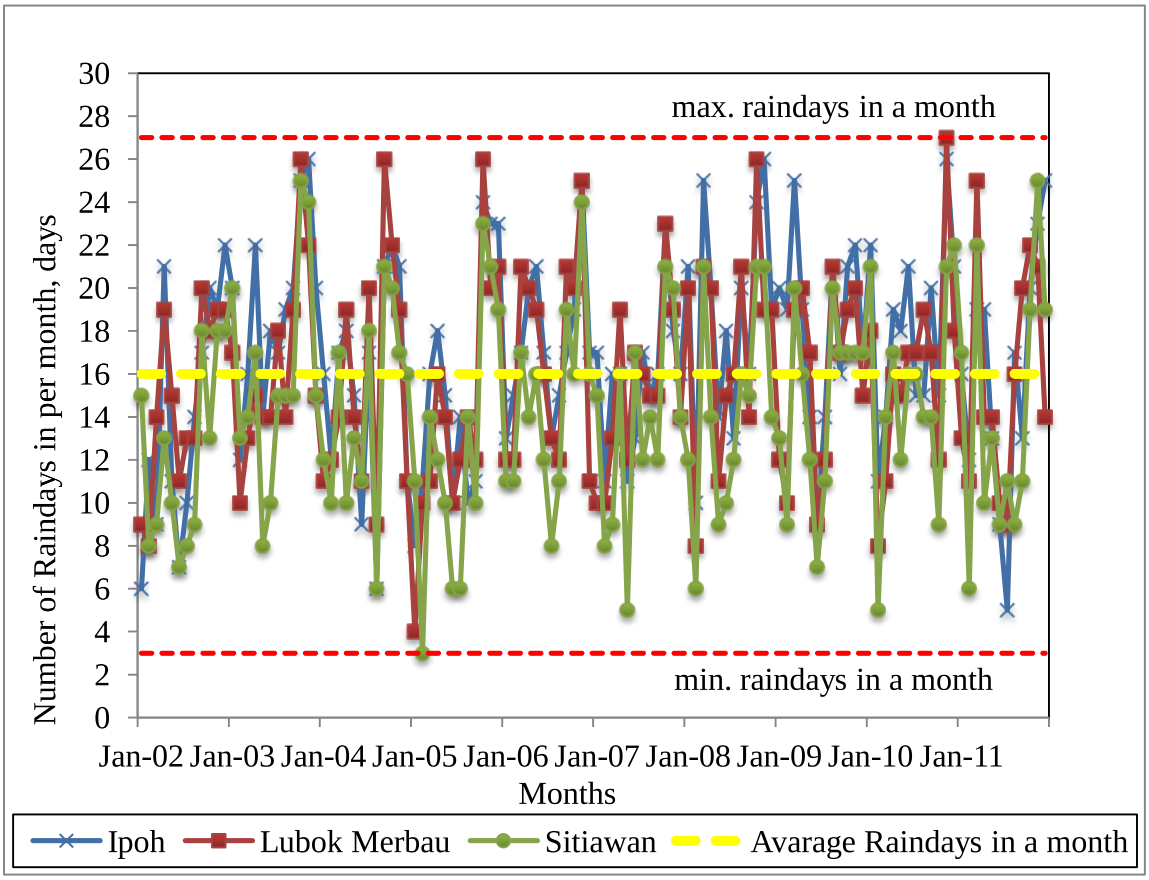

Figure 1.2: Frequency of raining day in Ipoh, Lubok Merbau and Sitiawan from 2002 to 2011

1.2 Problem Statement

1.2.1 Problem Identification

Forecast shows that fossil fuel depleting with its gas reserves estimated to last for another thirty years and oil reserves another nineteen years, therefore Malaysian government is strengthening the role of renewable energy as the fifth cornerstone of energy generation. This transformation offering opportunities to companies in energy management services to determine ways for saving energy and costs [3].

Laherrere studied show that the fossil fuel production is depleting [4]. From Figure 1.3 also we can see that the fuel cannot support the population demand since the population keeps increasing. Therefore, people should be doing something now to reduce oil dependence. In another words, move towards alternative energy.

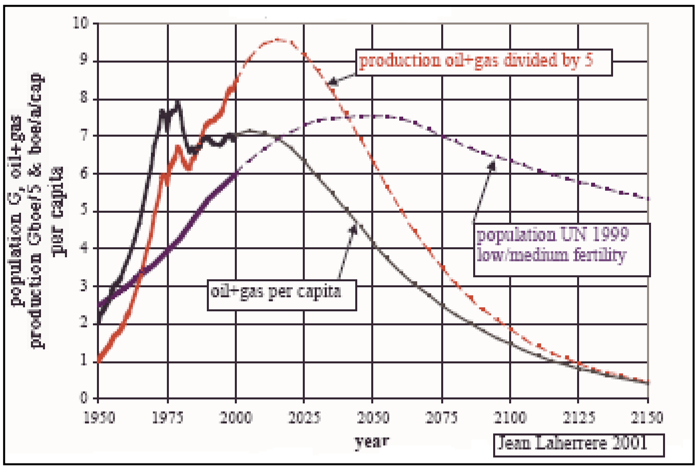

Figure 1.3: World scenario population and oil production per capita [4].

The era the availability of cheap natural gas will come to an end. A lot of initiatives will have to be found to encourage investments in new supply alternatives.

1.2.2 Significant of the Project

Malaysia having heavy rain [5], the rainfall brings amount of potential energy which converts into kinetic energy when hit any surface then cause the vibration. The energy usually ignored due to low energy can be extract. In other hand, with rapid technologies development that led to large-scale use of autonomous sensors such as development in piezoelectric material give opportunity explore to unexploited energy

1.3 Objective and Scope of Study

The objectives of this study are to study the potential energy can be generated from raindrop and establish correlation between raindrop and energy generated. The research activities are listed below;

i. Define the vibratory movements of Polyvinylidene fluoride film central nodes after drop impact.
ii. Define the strain of Polyvinylidene fluoride film after drop impact.
iii. Calculate theoretical potential electrical energy compare the result with previous study.
iv. Calculate the potential electrical energy that can be generated using Perak's rainfall data from 2002 until 2011.

The scope of study focuses on estimating the potential electrical energy that can be generated from raindrop impact by using polyvinylidene fluoride film. The data of Perak's rainfall amount from 2002 to 2011 to be used.

1.4 The Relevancy of the Project

Dependent mainly on oil and gas for half a century, Malaysia has started to realize and notice the importance to adopt renewable energy in the energy mix and continuously reviewed its energy policy to ensure sustainable energy supply and security. This project will be a part of supporting government effort on creating new alternative energy source. The overall approach is addressing the potential of rainfall as new alternative energy source to be commercialized.

1.5 Feasibility of the Project within the Scope and Time frame

This project mainly focuses on mechanical structure approaches and numerical method which required student to be more familiar and applying all knowledge. Simple experiment will be done to validate result and analyze the potential improvement. Therefore, it is possible to be completed in time frame by adopting successful references.

CHAPTER 2

LITERATURE REVIEW AND THEORY

2.1 Small- Scale Energy Source

Piezoelectric material had been established as it as most recommended material to abstract small scale energy which useful electrical energy that can be used to power wearable electronic devices. From a paper on piezoelectric energy harvesting, Christopher said that four proof-of-concepts Heel Strike Generators were developed for converting the mechanical energy of walking into electrical energy.

"As we mentioned in the pending paper, the critical challenge for piezoelectric energy harvesting is how to harvest electrical power on the order of tens of milliwatts to several watts, which is good enough for powering most portable devices, from any kinds of vibration and motion at any ranges of vibration frequencies (off-resonance mode harvesting technology is needed)," Xu told *PhysOrg.com*. "The new piezoelectric transducer addresses several critical issues from energy absorption, coupling, and conversion efficiency to overcome those challenges."[6]

"Piezoelectric energy harvesting is a multidisciplinary issue to be addressed from the considerations of mechanical engineering, electrical engineering, material science, and system engineering," Xu said. "For each individual mechanical vibration or motion resource, a specific device is designed to get an optimized electrical energy output. Our team is confident that we can move the energy harvesting technology into a new era." [6]

The Xu’s statement also had been address by Erturk and Inmann in their paper, a distributed parameter electromechanical model for cantilevered piezoelectric energy harvesters. They conclude that the literature includes several single degree-of-freedom models, a few approximate distributed parameter models and even some incorrect approaches for predicting the electromechanical behavior of these harvesters [7].

A project about theoretical on harvesting raindrop energy had been done by Romain Guigon, Jean – Jacques Chaillout, Thomas Jager and Ghislain Despesse. The objective of this paper was mechanical sizing of the structure used to optimize the transfer of deformation energy from the drop to the piezoelectric polymer by considering sensitivity of piezoelectric membrane towards surface impacts. The method approach was defining the potential deformation from drop impact by applying Law of Conservation of Energy. Self-written vibration modeling of vibratory movements of the impacted cable was obtained by applying the fundamental principle of dynamics to each node. Applying numerical methods of Runge-Kutta Algorithm, the result of the evolution over time of the amplitude of cable deformation was compared to ANSYS simulation. Using Navier-Bernoulli assumption, mechanical deformations were calculated which the average structure strain with variation of pre-stressing force towards the membrane surface. Then, predicted electrical quantities were obtained via mechanical-electric model in order to optimize the structure. Result concluded to use 25µm thick PVDF due the respond amount of electrical energy recovered is proportional to the kinetic energy. Therefore, it appears that, to effectively recover energy from raindrops using piezoelectric material, the material used must be very thin, not pre-stressed and with a width slightly smaller than the maximum diameter of the droplet [8].

A project have been done by Jedol Dayou, Man-Sang C., Dalimin M.N. and Wang S on Generating Electricity Using Piezoelectric The purpose of project was to study the potential of piezoelectric material as a power generator for daily low power electrical appliances. Piezoelectric ceramic material, Lead Zirconate Titanate (PZT) was the subject of study. Methods approach was theoretical development and stimulation to predict the power output from piezoelectric film attached to beam by using Eular-Bernoulli method. The experiment was run to compare the result. The output of this project was the power output was very low in the range of 0.2µm which is not practical to direct application. However, the root-mean-squared voltage founded as 1.18V which means it high enough to store the generated electricity into a small nickel metal hydride battery [9].

A paper written by Christopher A Howells about Piezoelectric energy harvesting .The paper is focusing on designing a system to generate 0.5W of power at 1Hz step rate by using proof-of-concept Heel Strike Generator. Each Heel Strike Generator utilizes four piezoelectric elements (each one being a Lead Zirconate Titanate (PZT- 5A) Bimorph Crystal Stack) to convert mechanical motion into electrical power in the form factor of the heel of a boot, where as the user walks, electrical power is generated. As a result the average power output over each compression appears to be steady and independent of the stroke compression and external [10].

2.2 Characteristic of Raindrops

Allocating alternative sources of energy is forcing genius to have extraordinary efforts which needed to use everything from sun to the motion of the ocean. But there is still one unexploited source of renewable energy which always neglected: rain. Raindrops have high amount of kinetic energy during the collision to the ground, which can be proven by soil crusting after raining which illustrated in Figure 2.1. During a rainfall, millions of drops fall at speeds up to 30 feet per second. Without raindrops, little soil erosion would be caused by water. Raindrops explode like tiny bombs, splashing water and soil particles as high as 3 feet and as far to the side as 5 feet, and breaking soil aggregates where the soil surface is not protected. Small aggregates and soil particles can be carried down slopes and off fields where the soil surface is not protected. Crop residue on the surface can prevent most soil loss [11].

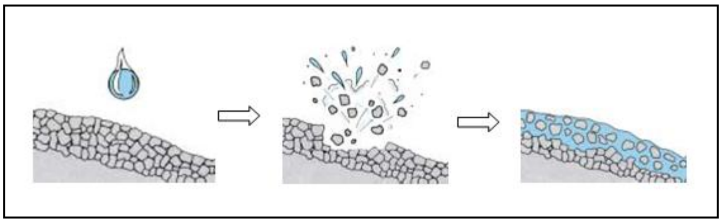

Figure 2.1: How raindrops falling on unprotected soils can result in soil displacement

Generally there are three different types of behaviors can be observed during drop impact on a solid surface which are splashing, spreading and bouncing as shown in Figure 2.2. Drops impinging on solids can adhere to or bounce off the surface and can break up after impact or it can spread smoothly. An obvious difference is between processes that cause a disintegration of the drop and those that do not [12].

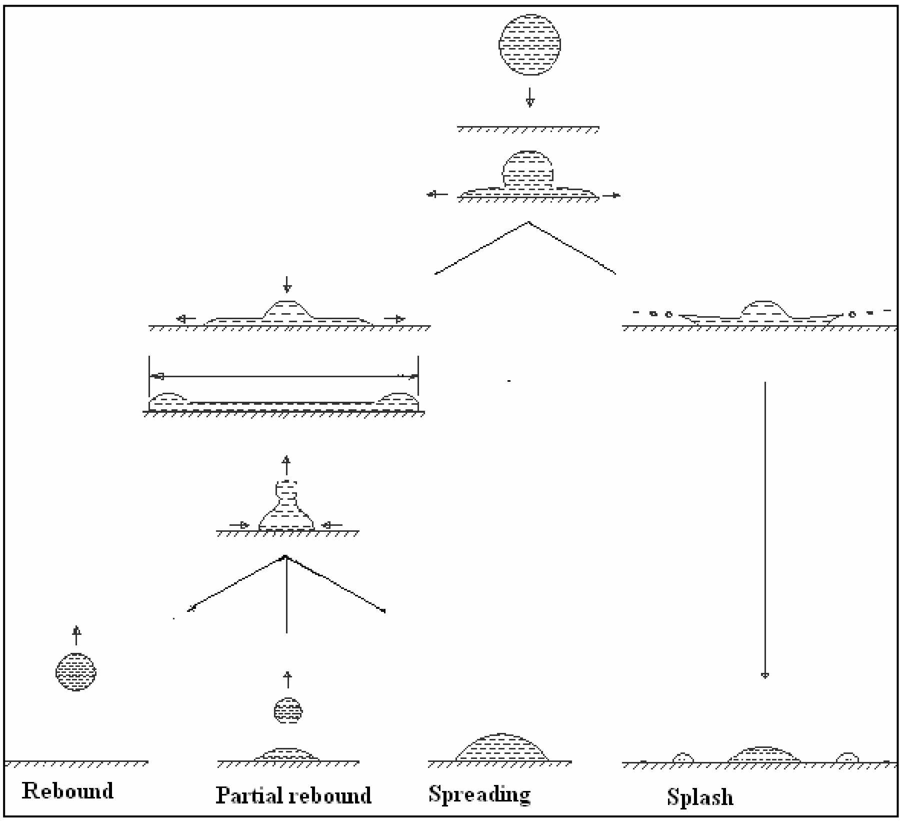

Figure 2.2: Scenarios of drop impact on a solid surface [12]

Many studies had been carried out to predict the behavior of raindrops. One said that behavior of raindrop can be easily demonstrating using rainfall simulator where the relationship of diameter of raindrop and terminal speed of fall is defined. Several equations had been published that describe the terminal speed of fall as a function of drop diameter. Best proposed $V_t = 10.30 - 9.65 (\exp -0.6d)$, which gives a good fit for diameters larger than 0.4mm, but predicts negative terminal velocities for very small drops [11].

Meanwhile, studies but Stow and Hadfiled established a splash parameter for occurrence of splash, which depends on the surface roughness. The correlation for splashing limit expresses as Re.31We.69 = ξ, where ξ, splash deposition value is dependent upon the surface roughness. Mundo et al determined the limit between the splash and deposition modes for rigid impact surface based on experiments. K = Oh*Re1.25 > 57.7 If K is larger than a critical empirical value of 57.7, and then it is in splashing regime. However, this empirical formula does not include other factors such as surface roughness, which is known to affect the contact angle between liquid drop and solid surface [11].

2.3 Characteristic of Polyvinylidene fluoride (PVDF)

PVDF is a synthetic semicrystalline polymer with piezoelectric properties that is consists of long molecular chains formed by a repetition of the molecular unit CH_2-CF_2 and alternating crystalline and amorphous layers. The molecular structure of PVDF is illustrate in Figure 2.3 The molecular weight of PVDF is typically between 60 and 70 kg/mol. PVDF's ferroelectric properties are making this polymer so unique. PVDF is considered to have a stronger piezoelectric response compared with other polymers and is considered easy to process into films [13].

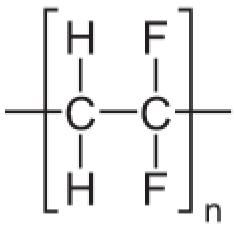

Figure 2.3: PVDF molecular structure

Other than its piezoelectric properties, polyvinylidene fluoride is a useful polymer due to its chemical stability, resistance to organic solvents, and high elastic modulus compared with other polymers. PVDF has shown to be very useful as a dielectric because of its high permittivity and dielectric strength and low dissipation factor. Compared to other polymers and other piezoelectric materials in general, PVDF has many benefits; some of them are listed below [13]:

- High rigidity, resists deformation
- Low glass transition temperature (no transitions between –45° and 170° C)
- Wide range of processing temperatures (185° – 250° C)

- Resistance to heat and combustion
- Resistance to ageing
- Resistance to abrasion
- Chemically inert.
- Non toxic
- Chemically resistant (highly polar solvents will cause slight swelling)
- Stability to radiation (UV, X-ray, Gamma)
- Excellent electrical insulator
- High Curie point (103° C, valuable for high temp piezoelectric applications)

PVDF is the most recommended piezoelectric polymer because of its well-characterized properties. Piezoelectric films are manufactured by mechanically drawing and polarizing extruded sheets. The extruded films are stretched on calendaring rolls as they cool, in meantime polarized using strong electrical fields. The molecular structure of resulting films is well oriented to concentrate the piezoelectric effect uniaxially or biaxially depending on the drawing conditions. Because the response to an electric potential acts along the polymer backbone, the more molecular orientation that can be produced in the films, the stronger the piezoelectric response [14].

2.4 Theory

The basic idea is generate the electrical energy from mechanical energy by applying the principle of conservation energy or first law of thermodynamics; that energy cannot be created or destroyed, although it can be changed from one form to another [15].

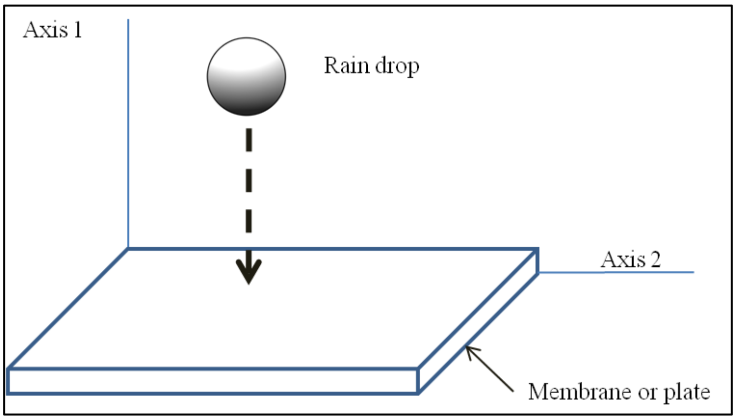

Figure 2.4: Schematic of raindrop energy harvesting system

During raining, illustrated in Figure 2.4, water drop stored high potential energy fall down with high speed, when it in contact with the cable, the raindrop will precipitate and the energy transfer to the cable which cause vibration of piezoelectric cable. Deformation of cable during the vibration provides stress to the piezoelectric structure that induces the electricity. Figure 2.5 shows the conservation of energy from mechanical energy; potential and kinetic energy to electrical energy involved in this system.

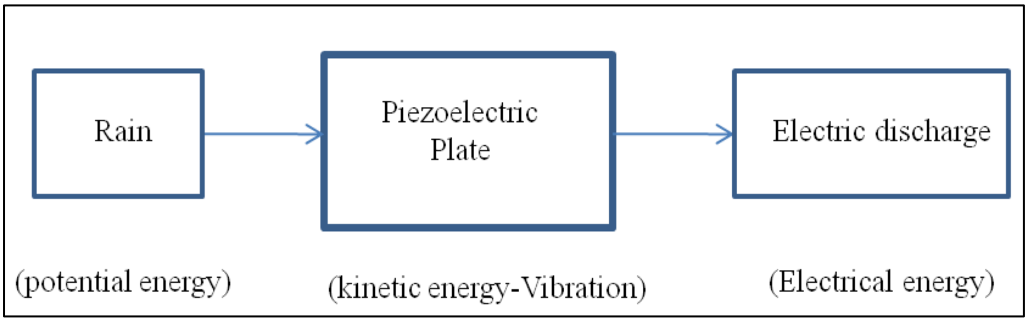

Figure 2.5: Block diagram of the raindrop energy harvesting system

Potential energy, V and kinetic energy, T can be expressed by;

$$\boldsymbol{V = mgh} \quad , \qquad \text{(Eq. 2.1)}$$

$$\boldsymbol{T = \frac{1}{2}mv^2} \qquad \text{(Eq. 2.2)}$$

where, *m* is the mass of raindrop, *g* is gravitational force, *h* is height and *v* is speed of raindrop . Apply the Newton Second's Law and Hooke's Law;

$$F = ma = m\frac{dv}{dt} \qquad \text{(Eq. 2.3)}$$

$$F = k\Delta t \qquad \text{(Eq. 2.4)}$$

where, a is acceleration, k is stiffness of piezoelectric and Δx is deformation of the cable. By definition of power, rate of energy in term of time;

$$Power = \frac{\frac{1}{2}mv^2}{time} = \frac{1}{2}\frac{k^2}{m}\left[\frac{dv}{dt}\right] \qquad \text{(Eq. 3.5)}$$

CHAPTER 3

METHODOLOGY

3.1 Process Flow Diagram

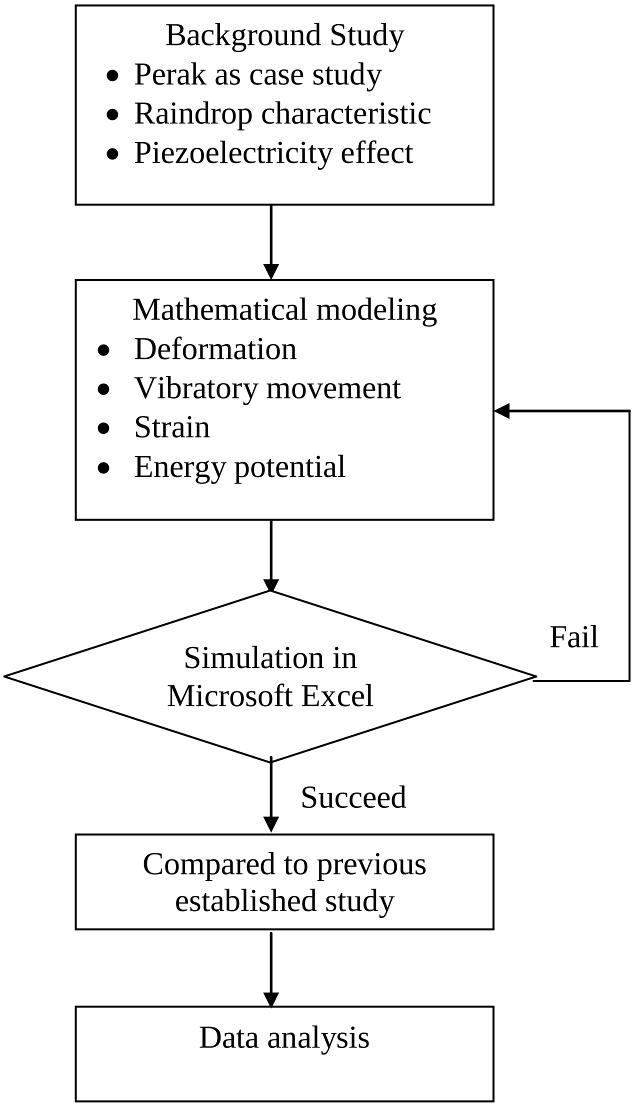

Figure 3.1: Project process flow diagram

3.1.1 Background Study

The project started by doing background study to see rainfall trend in Perak, focusing at Ipoh, Sitiawan and Lubok Merbau. Buying information from Malaysia Meteorology Department, monthly rainfall amount can be viewed and analyzed to see the trend of rainfall occurred in Perak from 2002 to 2011. Besides, deep studies had been done on raindrop and polyvinylidene fluoride (PVDF) to see their characteristics and properties.

3.1.2 Mathematical Modeling

By referring to main reference and basic theories, the mathematical model is developed to define the structure deformation, vibratory movement, strain and potential energy exerted.

3.1.3 Simulation

In this project, Microsoft Excel is chosen to simulate the mathematical modeling. In order to solve the movement equations, Runge-Kutta algorithm is selected due to easy programming, stable solution, and easy modification of steps and of the initial conditions by took the positions and speeds of all the nodes as unknowns.

3.1.4 Comparing the result

As the result obtained, the result is compared to previous study to verify the result since the experiment cannot be run due to purchasing material problem. There will be slightly differences of the result although the methodology used is similar due to some constants used are not same.

3.1.5 Data analysis

The results obtained were analyzed to see the significant of this project as a projector on new alternative energy and discuss it potential as new alternative energy, either it can be commercialized or not.

3.2 Mathematical Modeling

This project will study about polyvinylidene fluoride film which can be model in 31-mode type, transverse mode type. In order to know the electrical energy can be generated the strain and then vibratory movement of the polyvinylidene fluoride film need to be defined. Since this study using thin PVDF film, the definition of distance variation in cable meshing can be shown below;

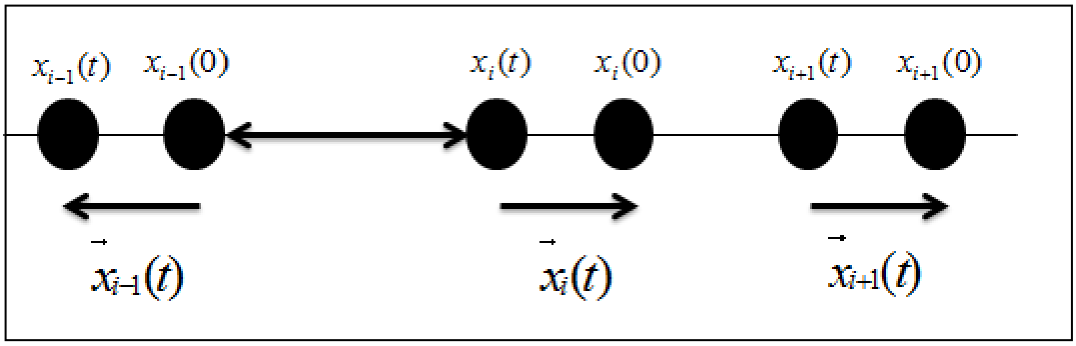

Figure 3.2: Illustration of distance variation

Based on Figure 3.2, the vibratory movement of the impacted cable is obtained by applying the fundamental principle of dynamics to each node;

$$m_i(\ddot{x}_i\vec{\imath} + \ddot{y}_i\vec{\jmath}) = \vec{P}_i + \vec{T}_{i+1} + \vec{T}_{i-1} + \vec{A}_{i+1} + \vec{A}_{i-1} + \vec{A}_i \quad \text{(Eq. 3.1)}$$

where P is weight, T is traction or compression exerted by the node and A is damping force. The force exerted on each node shows in Figure 3.3.

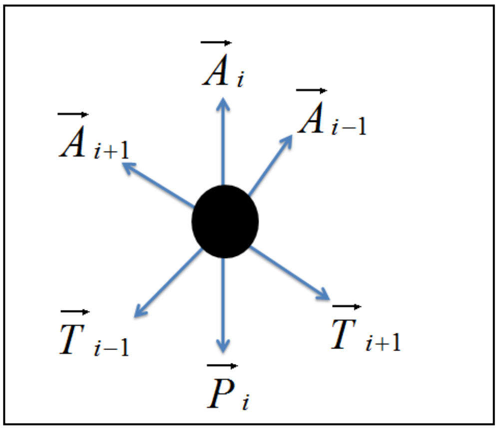

Figure 3.3: Forces acting on node

To stimulate the movement equation above, use Runge-Kutta algorithm method to define the unknown values.

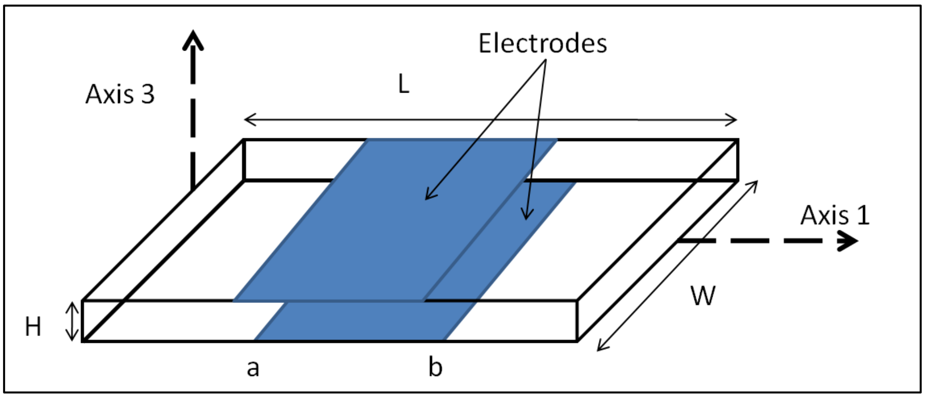

Figure 3.4: Diagram of piezoelectric cable covered by electrodes

Based on Figure 3.4, the piezoelectric effects can derives in form of relative strain.

$$\boldsymbol{S_{ave}(t) = \frac{1}{b-a}\int_a^b S(x_i\,, t)dx} \qquad \text{(Eq. 3.2)}$$

According to the Courbon Jean, the possible extract electrical energy expressed by [16];

$$U_{elec} = k^2 \frac{Y\,\vartheta}{2}\, S^2 \qquad \text{(Eq. 3.3)}$$

where, k is the material coupling coefficient ,Y its Young's modulus, ϑ its active volume and S its average volume deformation variation during the impact. [16]. From there, according Guigon *et al*. paper, the electrical energy in PVDF material can be formulated as follows ;

$$U_{elec} = k_{31}^2 \frac{Y_{PVDF} H_0 W_0 (b-a)}{2} S_{ave} \qquad \text{(Eq. 3.4)}$$

3.3 Model Simulation in Microsoft Excel

i) Inter-structure deformation

By considering pre-stressing, T_0 of 0.1N during embedding, the inter-structure/inter-node distance becomes:

$$\Delta x = \Delta x_0 + \frac{T_0}{(n-1) Y_{PVDF} \frac{WH}{L}} \qquad \text{(Eq. 3.5)}$$

ii) Membrane/film deformation

Each node, i is subjected to four forces; its own weight, P_i , traction/compression, T_i , damping force by internal frictions in material , A_{i+1} and damping force by structure interaction, A_i. Where;

$$\vec{T}_{i+1} = K[\sqrt{(x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2} - \Delta x]\vec{u}_{i+1} \quad \text{(Eq. 3.6)}$$

$$\vec{A}_{i+1} = -\beta(\dot{x}_{i+1} - \dot{x}_i)\vec{u}_{(i+1)x}\vec{\imath} - \beta(\dot{y}_{i+1} - \dot{y}_i)\vec{u}_{(i+1)y}\vec{\jmath} \quad \text{(Eq. 3.7)}$$

$$\vec{A}_i = -6\mu_{air}(\Delta x + W)\dot{y}_i\vec{\jmath} \quad \text{(Eq. 3.8)}$$

Let $z = x + y$ in equation 3.1, the vibratory movement equation will be as in equation 3.9; make the equation in matrix form will make the simulation easier.

$$\ddot{\vec{z}}(t) = [m]^{-1}(\vec{P}(t) + [A]\dot{\vec{z}}(t) + [T]\vec{z}(t)) \quad \text{(Eq. 3.9)}$$

This mathematical, equation 3.9, is model require to simulate the fourth order Runge-Kutta method (RK4) for multidegree of freedom system because of easy programming, stable solution, easy modification of steps and of the initial conditions. By treating the displacements as well as velocities as unknowns, a new vector, $\vec{Z}(t)$ which defined as $\vec{Z}(t) = \begin{Bmatrix} \vec{z}(t) \\ \dot{\vec{z}}(t) \end{Bmatrix}$ so that

$$\vec{Z}(t) = \begin{Bmatrix} \dot{\vec{z}} \\ \ddot{\vec{z}} \end{Bmatrix} = \begin{Bmatrix} \dot{\vec{z}} \\ [m]^{-1}(\vec{P} + [A]\dot{\vec{z}} + [T]\vec{z}) \end{Bmatrix} \quad \text{(Eq. 3.10)}$$

Rearranged to obtain

$$\vec{Z}(t) = \begin{bmatrix} [0] & [I] \\ [m]^{-1}[T] & [m]^{-1}[A] \end{bmatrix} \begin{Bmatrix} \vec{z}(t) \\ \dot{\vec{z}}(t) \end{Bmatrix} + \begin{Bmatrix} 0 \\ [m]^{-1}\vec{P}(t) \end{Bmatrix} \quad \text{(Eq. 3.11)}$$

Which is $\dot{\vec{Z}}(t) = \vec{f}(\vec{Z}, t)$ with this, the recurrence formula to evaluate $\vec{X}(t)$ at different grid point t_i according to the RK4 becomes [17]

$$\vec{Z}_{i+1} = \vec{Z}_i + \frac{1}{6}[\vec{K}_1 + 2\vec{K}_2 + 2\vec{K}_3 + \vec{K}_4] \quad \text{(Eq. 3.12)}$$

Where

$$\vec{K}_1 = h\vec{f}\left(\vec{Z}_i, t_i\right) \quad \text{(Eq. 3.13)}$$

$$\vec{K}_2 = h\vec{f}\left(\vec{Z}_i + \frac{1}{2}\vec{K}_1, t_i + \frac{1}{2}h\right) \quad \text{(Eq. 3.14)}$$

$$\vec{K}_3 = h\vec{f}\left(\vec{Z}_i + \frac{1}{2}\vec{K}_2, t_i + \frac{1}{2}h\right) \quad \text{(Eq. 3.15)}$$

$$\vec{K}_4 = h\vec{f}\left(\vec{Z}_i + \vec{K}_3, t_i\right) \quad \text{(Eq. 3.16)}$$

CHAPTER 4

RESULTS AND DISCUSSION

Table 4.1 shows the initial condition of inter-structure on PVDF structure under 0.1N pre-stressing. It shows that the distance between nodes before the raindrop hit the surface of the piezoelectric material. The differences of the distance among the node are due to its own weight and traction force exerted by the nodes.

Table 4.1: The inter-structure distance under 0.1N pre-stressing

node	Δxi
1	0.000000
2	0.007500
3	0.005000
4	0.004167
5	0.003750
6	0.003500
7	0.003333
8	0.003214
9	0.003125
10	0.003056
11	0.003000
12	0.002955
13	0.002917
14	0.002885
15	0.002857
16	0.002833
17	0.002813
18	0.002794
19	0.002778
20	0.002763
21	0.002750
22	0.002763
23	0.002778
24	0.002794
25	0.002813
26	0.002833
27	0.002857
28	0.002885
29	0.002917
30	0.002955
31	0.003000
32	0.003056
33	0.003125
34	0.003214
35	0.003333
36	0.003500
37	0.003750
38	0.004167
39	0.005000
40	0.007500

After simulation of vibratory movement of the film, Table 4.2 shows the results of movement of central node under pre-stressing of 0.1N. From Guigon *et al.*

research paper, at t = 50ms, the drop impacts the cable which cause the film start to vibrate. Therefore, for this study, to simulate the vibratory movement, the initial time used is 50ms which the result shows in Figure 4.1. The vibratory movement illustrate in Figure 4.1, the decline of the trend is due to internal damping forces of air/structure interaction.

Table 4.2: Result of movement of film according to pre-stressing of 0.1N

Δt, s	z, µm	Δt, s	z, µm	Δt, s	z, µm	Δt, s	z, µm
0.500	50.13	0.623	-36.41	0.747	14.83	0.870	-12.27
0.503	-50.29	0.627	33.69	0.750	-21.83	0.873	11.38
0.507	48.12	0.630	-33.11	0.753	15.08	0.877	-14.39
0.510	-48.25	0.633	34.35	0.757	-17.65	0.880	9.93
0.513	50.91	0.637	-35.29	0.760	15.01	0.883	-13.11
0.517	-47.25	0.640	31.54	0.763	-17.07	0.887	9.85
0.520	47.34	0.643	-34.97	0.767	14.95	0.890	-11.64
0.523	-49.96	0.647	28.73	0.770	-15.99	0.893	9.69
0.527	47.41	0.650	-29.03	0.773	14.23	0.897	-13.09
0.530	-47.78	0.653	31.97	0.777	-16.84	0.900	9.41
0.533	47.19	0.657	-31.24	0.780	13.83	0.903	-12.01
0.537	-45.97	0.660	28.53	0.783	-16.73	0.907	8.31
0.540	48.37	0.663	-30.24	0.787	14.48	0.910	-10.87
0.543	-47.21	0.667	25.83	0.790	-14.92	0.913	9.42
0.547	44.89	0.670	-27.01	0.793	14.17	0.917	-10.53
0.550	-48.33	0.673	26.38	0.797	-15.81	0.920	9.30
0.553	44.08	0.677	-27.61	0.800	13.39	0.923	-10.38
0.557	-41.37	0.680	24.79	0.803	-14.83	0.927	9.27
0.560	47.05	0.683	-25.82	0.807	13.43	0.930	-11.17
0.563	-46.43	0.687	22.46	0.810	-14.51	0.933	9.45
0.567	46.81	0.690	-26.17	0.813	13.75	0.937	-10.01
0.570	-41.23	0.693	22.75	0.817	-15.02	0.940	9.91
0.573	43.35	0.697	-23.19	0.820	12.64	0.943	-11.04
0.577	-40.87	0.700	21.09	0.823	-13.01	0.947	9.48
0.580	39.82	0.703	-22.18	0.827	11.71	0.950	-10.81
0.583	-43.09	0.707	21.86	0.830	-15.67	0.953	9.71
0.587	42.61	0.710	-22.47	0.833	13.59	0.957	-11.17
0.590	-44.13	0.713	19.36	0.837	-14.82	0.960	9.94
0.593	42.91	0.717	-22.06	0.840	12.47	0.963	-10.26
0.597	-39.37	0.720	19.47	0.843	-12.79	0.967	10.57
0.600	34.57	0.723	-21.32	0.847	12.63	0.970	-12.56
0.603	-37.74	0.727	16.21	0.850	-15.34	0.973	9.46
0.607	38.19	0.730	-21.74	0.853	10.11	0.977	-10.66
0.610	-41.96	0.733	17.33	0.857	-15.41		
0.613	39.07	0.737	-21.59	0.860	10.37		
0.617	-42.26	0.740	17.78	0.863	-12.53		
0.620	33.84	0.743	-18.93	0.867	10.78		

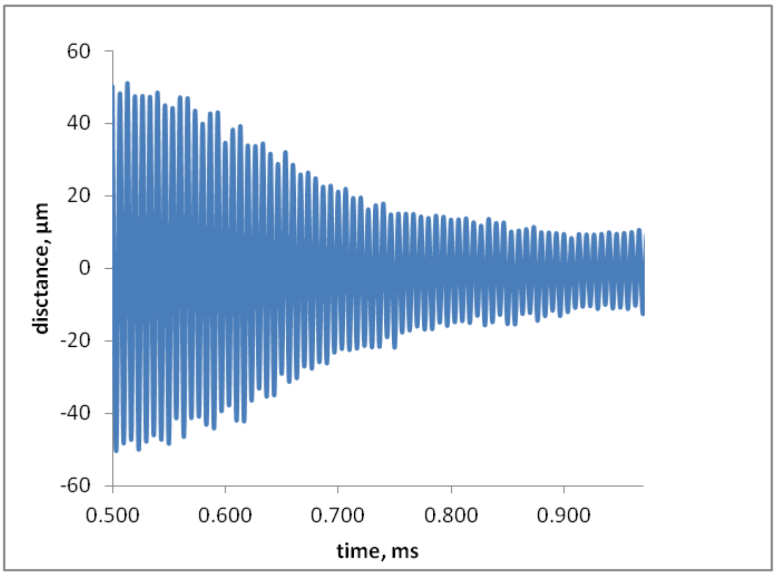

Figure 4.1 Movement of the film versus time according to pre-stressing of 0.1N

As the piezoelectric is operating in 31mode, the only component of the deformation tensor that needs to be considered is strain of structure which expressed by equation 3.2; where

$$S_r(x_i, t) = S(x_i, t) - S(x_i, t - \Delta t) \qquad \text{(Eq. 4.1)}$$

$$S(x_i, t) = \frac{2(\Delta x - \Delta x_0) + (\bar{x}_{i+1} - \bar{x}_{i-1})}{2.\Delta x_0} + \frac{(\bar{y}_{i+1} - \bar{y}_i)^2 + (\bar{y}_i - \bar{y}_{i-1})^2}{4\Delta x_0 \Delta x} \qquad \text{(Eq. 4.2)}$$

b=L and a=0 at maximum time and centre node, i=20 therefore,

$$S_{ave} = \frac{1}{0.1}\int_0^{0.1} \frac{2(\Delta x - \Delta x_0) + (\bar{x}_{21} - \bar{x}_{19})}{2.\Delta x_0} + \frac{(\bar{y}_{21} - \bar{y}_{20})^2 + (\bar{y}_{20} - \bar{y}_{19})^2}{4\Delta x_0 \Delta x} dx \qquad \text{(Eq. 4.3)}$$

Therefore, the average strain S_{ave} is 0.06589 m/m. As a result potential electrical energy generated for every 25µm x 10cm film is theoretically is $0.904 \times 10^{-12} J \approx 0.9pJ$. Therefore, for every 2.5µm² area of PVDF film will generate about $0.9pJ$ of energy of 1mm of raindrop.

Table 4.3: Comparison of this project result with Guigon R research paper of the electrical generated.

	Guigon *et al*. research paper	This project
Electrical energy generated	1.76pJ	0.9pJ

Table 4.3 shows that the comparison of the result of this project with the published research paper, Harvesting raindrop energy: theory (2007) by Guigon *et al*.

The difference is due to the difference value of material coupling coefficient used. The calculation for material coupling coefficient is $k_{31}^2 = d_{31}^2 / (s^E_{11}\ \varepsilon^T_{33})$ where $s^E_{11} = 1 / Y^E_{11}$ In this project, the value of coefficient used was possibility smaller than Guigon *et al.* paper which direct to smaller electrical energy generated since similar methodology used.

Table 4.4: Estimation of potential electrical energy generated in Ipoh, Lubok Merbau and Sitiawan for every 1m² plate of PVDF

Year	Ipoh		Lubok Merbau		Sitiawan	
	Rainfall Amount, mm	Potential Energy, mJ	Rainfall Amount, mm	Potential Energy, mJ	Rainfall Amount, mm	Potential Energy, mJ
2002	1987.8	0.28	1665.5	0.23	1653.2	0.23
2003	3463.3	0.49	1671.6	0.24	2065.4	0.29
2004	2743.6	0.39	1866.3	0.26	1676.2	0.24
2005	2063.6	0.29	1686.2	0.24	1986.4	0.28
2006	3278.3	0.46	1827.2	0.26	2000.2	0.28
2007	2913.1	0.41	1642.4	0.23	1408.6	0.20
2008	3528.8	0.50	2391.8	0.34	2224.5	0.31
2009	3096.2	0.44	2110.4	0.30	2072.0	0.29
2010	3189.1	0.45	2139.6	0.30	1517.6	0.21
2011	2582.3	0.36	2182.4	0.31	2471.1	0.35

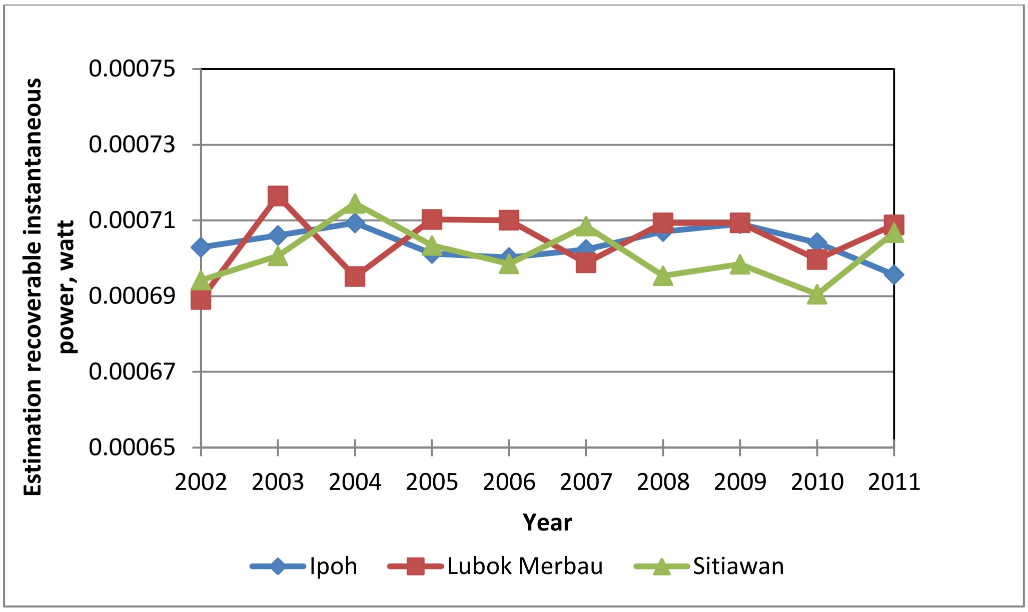

Figure 4.2: Graph of estimation of recoverable instantaneous power generated in Ipoh, Lubok Merbau and Sitiawan for every 1m² plate of PVDF

For 1mm of raindrop will generate 0.9pJ of electrical energy. The in Perak the maximum electrical energy generated is 0.49mJ which shown in table 4.4 for every 1m² of PVDF plate. According to Guigon et al. take the time average between two drops; less than 1s, compared to recovery time, slightly equal to 2 ms, the total electrical energy should be the integral of that produced by all the single drops shows in figure 4.2. There we can know that the maximum power can be generate is about 0.7mW for every 1m² PVDF plate.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Energy is now becoming major concern apart of environmental concern. It is impossible to replace the mainstream energy by use of non conventional energy but it is not impossible to have new alternative energy, although the output is still small, in supporting for our better future life. Therefore, the ignorance of small amount of energy is not acceptable.

This project shows that small amount of energy can be successfully harnessed by PVDF film which makes this project may not be feasible and economically viable for full scale power production yet. According to R Guigon et al., it appears that, to effectively recover energy from raindrops using piezoelectric material, the material used must be very thin and a width slightly smaller than maximum diameter of impacting drop. Besides, recent rapid development in advanced piezoelectric material would make the energy harnessing more feasible for commercialization.

5.2 Recommendation

Further in-depth researches and studies are recommended to make sure that the abundant resource such as raindrop is not wasted. Further work can be focused on the innovation of new piezoelectric harvesters capable harvesting enough energy to power different types of portable devices from the environment.

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APPENDICES

APPENDIX-I: FYP 1 and FYP 2 Gantt Chart

No	Detail	1	2	3	4	5	6	7	MID SEMESTER BREAK	8	9	10	11	12	13	14	SEMESTER BREAK	15	16	17	18	19	20	21	MID SsEMESTER BREAK	22	23	24	25	26	27	28	29
1	Selection of topic (kick-off)																																
2	Background study and Literature review																																
3	Data gathering																																
4	Submission of Extended proposal defense																																
5	Mathematical Modeling									1																							
6	Proposal Defense																																
7	Simulation of model -Inter-structure deformation -Membrane/film deformation -Strain -Electrical Energy													2																			
8	Submission of Interim Draft Report																																
9	Submission of Interim Report																																

FYP 1 and FYP 2 Gantt Chart (Continue)

10	Comparing result to previous study																									Blue							
11	Submission of progress report								MID SEMESTER BREAK								SEMESTER BREAK								MID SsEMESTER BREAK	Blue (3)							
12	Documentation -poster -thesis & technical report -Presentation preparation																									Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
13	Pre-Edx																												Blue				
14	Submission of Draft Report																													Blue			
15	Submission of Dissertation report (soft bound)																														Blue		
16	Submission of Technical paper																														Blue		
17	Oral Presentation																															Blue	
18	Submission of Project dissertation (hard bound)																																Blue

Milestones:

Yellow	Process
Blue	Suggested milestone by FYP committee
(1)	Milestone to accomplish objective number 1 and 2
(2)	Milestone to accomplish objective number 3 and 4
(3)	Milestone to accomplish objective number 5

APPENDIX-II: Data from Malaysia Meteorology Department on Monthly Rainfall Amount

JABATAN METEOROLOGI MALAYSIA

Station : Ipoh Lat. : 04° 34' N Long. : 101° 06' E Ht. above M.S.L. : 40.1 m

Records of Monthly Rainfall Amount

Unit : mm

Month / Year	Jan.	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2002	44.2	90.2	130.2	340.6	141.2	123.0	68.8	194.0	121.0	264.4	238.7	231.5	1987.8
2003	180.2	125.0	276.7	237.4	210.4	277.0	425.6	335.8	189.2	515.4	441.4	249.2	3463.3
2004	293.8	307.4	155.4	317.0	283.8	33.6	183.6	91.2	396.0	185.4	330.6	165.8	2743.6
2005	36.6	100.2	172.6	261.8	226.4	122.0	215.2	89.6	88.0	260.8	211.6	278.8	2063.6
2006	202.8	163.6	266.6	217.1	428.6	259.2	146.8	203.2	175.8	262.6	618.2	333.8	3278.3
2007	251.2	242.4	364.2	243.0	42.6	248.4	328.2	145.0	254.8	359.3	305.0	129.0	2913.1
2008	357.6	113.0	425.8	221.0	123.4	268.8	202.6	340.6	330.4	405.6	338.0	402.0	3528.8
2009	349.2	254.0	261.8	360.8	161.2	162.0	269.8	252.0	194.0	213.6	373.6	244.2	3096.2
2010	286.0	241.8	191.8	304.2	366.4	303.0	173.8	295.4	145.6	190.4	378.5	312.2	3189.1
2011	272.2	212.6	308.8	301.3	207.6	45.6	45.8	249.8	185.4	185.2	315.4	252.6	2582.3

Records of Number of Raindays

Month / Year	Jan.	Feb.	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2002	6	12	9	21	11	7	10	14	17	20	19	22	168
2003	20	12	16	22	14	18	17	19	20	25	26	20	229
2004	16	12	17	18	15	9	17	6	21	22	21	11	185
2005	8	11	16	18	15	10	14	10	11	24	23	23	183
2006	13	15	17	20	21	17	13	15	17	19	25	17	209
2007	17	11	16	16	11	13	17	15	16	23	18	16	189
2008	21	10	25	20	14	18	13	20	16	24	26	19	226
2009	20	19	25	19	14	9	14	21	16	21	22	17	217
2010	22	11	14	19	18	21	15	15	20	15	26	21	217
2011	16	12	19	19	13	9	5	17	13	20	23	25	191

JABATAN METEOROLOGI MALAYSIA

Station : Lubok Merbau   Lat. : 04° 48' N   Long. : 100° 54' E   Ht. above M.S.L. : 77.5 m

Records of Monthly Rainfall Amount

Unit : mm

Month / Year	Jan.	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2002	67.8	32.0	120.9	341.8	110.9	61.2	84.4	115.3	175.2	170.1	147.4	238.5	1665.5
2003	71.4	94.1	129.0	186.5	97.6	110.7	107.9	85.4	108.8	240.2	286.2	153.8	1671.6
2004	144.4	270.3	80.4	225.1	125.5	70.1	178.1	83.6	202.4	192.7	209.2	84.5	1866.3
2005	3.9	104.7	37.0	174.0	218.9	94.8	159.9	124.0	85.4	287.4	186.2	210.0	1686.2
2006	71.8	67.4	226.4	285.6	104.6	116.2	94.8	23.0	94.8	241.2	326.4	175.0	1827.2
2007	140.0	62.6	156.4	124.8	98.4	135.2	177.4	116.8	127.4	232.4	179.2	91.8	1642.4
2008	168.0	101.2	343.0	174.8	88.6	220.6	230.6	235.8	159.2	375.0	112.2	182.8	2391.8
2009	90.2	47.6	267.8	226.0	122.6	103.2	63.8	218.8	214.2	268.8	311.6	175.8	2110.4
2010	194.6	45.4	176.8	172.4	131.0	246.2	189.6	112.8	149.4	198.2	380.4	142.8	2139.6
2011	43.6	222.2	426.2	141.4	86.6	46.6	114.4	237.0	183.6	278.4	238.8	163.6	2182.4

Records of Number of Raindays

Month / Year	Jan.	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2002	9	8	14	19	15	11	13	13	20	18	19	19	178
2003	17	10	13	15	14	14	18	14	19	26	22	15	197
2004	11	12	14	19	14	11	20	9	26	22	19	11	188
2005	4	10	11	16	14	10	12	14	12	26	20	21	170
2006	12	12	21	20	19	16	13	12	21	20	25	11	202
2007	10	10	13	19	12	17	16	15	15	23	19	14	183
2008	20	8	21	20	11	15	16	21	14	26	19	19	210
2009	12	10	19	20	17	9	12	21	17	19	20	15	191
2010	18	8	11	16	15	17	17	19	17	12	27	18	195
2011	13	11	25	14	14	10	9	16	20	22	21	14	189

JABATAN METEOROLOGI MALAYSIA

Station : Sitiawan Lat. : 04° 13' N Long. : 100° 42' E Ht. above M.S.L. : 7.0 m

Records of Monthly Rainfall Amount

Unit : mm

Month / Year	Jan.	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2002	155.9	98.8	125.6	180.3	185.7	58.5	50.3	28.4	251.5	203.5	128.4	186.3	1653.2
2003	138.9	228.0	54.6	132.3	108.1	147.1	80.6	104.7	160.6	564.2	173.8	172.5	2065.4
2004	217.8	141.1	140.6	144.2	72.1	56.0	149.4	52.3	143.1	276.8	121.1	161.7	1676.2
2005	88.4	5.2	63.9	161.2	109.0	79.6	110.6	263.6	106.2	369.4	316.6	312.7	1986.4
2006	126.4	253.8	198.8	227.2	182.2	66.0	95.6	161.8	195.0	210.8	145.6	137.0	2000.2
2007	160.4	49.8	44.4	111.4	26.8	105.6	156.8	156.8	97.6	162.6	209.6	126.8	1408.6
2008	167.4	57.4	279.1	91.2	72.0	130.8	209.2	344.2	121.0	449.6	131.0	171.6	2224.5
2009	201.0	50.2	288.4	136.8	106.2	67.8	152.0	206.8	234.6	219.4	229.2	179.6	2072.0
2010	273.8	27.8	66.8	144.6	219.4	87.8	53.8	73.4	128.6	47.0	240.2	154.4	1517.6
2011	291.6	88.2	241.6	79.8	112.6	124.2	98.4	115.6	152.7	428.4	491.0	247.0	2471.1

Records of Number of Raindays

Month / Year	Jan.	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2002	15	8	9	13	10	7	8	9	18	13	18	18	146
2003	20	13	14	17	8	10	15	15	15	25	24	15	191
2004	12	10	17	10	13	11	18	6	21	20	17	16	171
2005	11	3	14	12	10	6	6	14	10	23	21	19	149
2006	11	11	17	14	16	12	8	11	19	16	24	16	175
2007	15	8	9	16	5	17	12	14	12	21	20	14	163
2008	12	6	21	14	9	10	12	16	15	21	21	14	171
2009	13	9	20	16	12	7	11	20	17	17	17	17	176
2010	21	5	14	17	12	16	16	14	14	9	21	22	181
2011	17	6	22	10	13	9	11	9	11	19	25	19	171