PROJECT SYNOPSIS FOR “STUDENT PROJECT-42ND SERIES”

PROJECT PROPOSAL REFERENCE NO. : 42S_BE_0869

1. Title Of The Project:
“Design & Fabrication Of Energy Harvester Using VIVACE”

2. Name Of The College & Dept.:
Vidyavardhaka College Of Engineering (VVCE) &Department Of Mechanical Engineering

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4. Keywords:
Energy crisis, Hydropower, Clean Energy, Vortex shedding, Vortex Induced Vibrations (VIV), Vortex Induced Vibrations Aquatic Clean Energy (VIVACE), Energy Harvester, CFD Simulation

5. Introduction / Background:
Massive industrialization and population growth have led to a surge in the global demand for energy in recent years. Electricity is the new currency and developing countries are in desperate need of insatiable units of electricity. There is so much potential in Hydropower which when harnessed efficiently can show a phenomenal way in addressing the energy crisis. The ramifications of conventional hydropower generation due to damming of water, change in flow of water, construction of roads and setting up of power lines are disastrous to aquatic ecosystem. How can engineers develop an energy harvester without unbalancing the aquatic ecosystem? Billions of units of power incessantly flow down rivers and streams, or wash up on shores, just to dissipate. It is also immensely challenging to harness: How can engineers tap this vast, restless resource to create sustainable energy that emulate fossil fuels and is compatible with existing power grids?

The answer to above questions is Vortex Induced Vibrations Aquatic Clean Energy (VIVACE). Energy crisis can be mitigated by utilizing the unused flow energy of water and producing electricity even in small scales. Vortex Induced Vibrations Aquatic Clean Energy (VIVACE) focuses on Clean Energy, making use of Vortex Induced Vibrations (VIV) to generate electricity. The analytical calculations
involved in design and fabrication process related to energy harvester are done. CFD simulations are done to obtain the feasible values of some important parameters involved in VIVACE.

6. Objectives:

- To produce clean and renewable energy.
- To obtain considerable amount of electricity during this era of depleting energy
- To extract energy in areas which have flowing river water and extract energy in small scales
- To familiarize with the concept of flow around cylindrical structure.
- To understand the vibration phenomena of cylindrical structure.
- To investigate the flow pattern characteristic around cylindrical structure using CFD

7. Methodology:

i. Background study:

- Vortex shedding: The phenomenon of Vortex shedding occurs when pairs of stable vortices are susceptible to small disturbances and become unstable at Re greater than 40. For these values of Re, the boundary layer over the cylinder surface will separate due to the pressure gradient forced by the divergent profile of the flow territory at the backside of the cylinder.
- Vortex Induced Vibrations (VIV): VIV result from vortices forming and shedding on the downstream side of a bluff body in a current. Vortex shedding alternates from one side to the other, thereby creating an oscillation / a vibration. The VIV phenomenon is non-linear. This property of VIV has huge implication as it can produce beneficial energy at high efficiency over a wide range of current speeds.

ii. Principle:

- Vortex Induced Vibration Aquatic Clean Energy (VIVACE): Vortex Induced Vibration Aquatic Clean Energy (VIVACE) replicates the features of fish movements. Fish curve their bodies to glide between the vortices shed by their bodies in front of them. Their muscle power alone cannot propel them forward through the water at the speed they go, so they ride in each other’s wake. Vortex induced vibrations are undulations that a rounded or cylinder-shaped object make in a flow of fluid, which can be air or water. The presence of the object puts twirls in the current’s speed as it glides by. This causes eddies or vortices which generate a pattern on either sides of the object. The vortices push and pull the object up and down or left and right, perpendicular to the current. VIVACE converts the hydrokinetic energy of currents into cylinder mechanical energy. The latter is then converted to electricity through electric power.
• Cross-Flow Vortex Induced Vibration: Cross-flow is the force component. The lift force ($F_L$) is in the cross-flow direction. The lift force develops when the vortex shedding begins and it varies at the vortex shedding frequency. The lift force causes the cross-flow vortex induced vibration.

![Figure 1: Sketch of Cross flow Vortex Induced Vibrations](image1)

iii. Principle parts:

1. Bluff Body (Cylinder)  
2. Rack  
3. Pinion  
4. Gear Coupled with DC generator

![Figure 2: CAD model of experimental set-up](image2)

iv. Working Principle of Energy Harvester:

![Figure 3: Enlarged view of gear coupled with Generator](image3)
As the cylinder (Bluff body) is subjected to hydro-energy, it tends to oscillate. The cylinder is fixed axially and cross flow Vortex Induced Vibrations takes place. A rack and pinion arrangement converts linear motion to rotational motion. The pinion drives the shaft, which rotates the alternator to generate power. Thus, electrical energy is obtained by continuous oscillation of the cylinder and DC output voltage is obtained.

v. Analytical Calculations:

1. Reynolds Number (Re):

\[
Re = \frac{DU}{v} = 25.4 \times 10^{-3} \times 1 / 0.89 \times e^{-6}
\]

\[
Re = 28539.32
\]

2. Strouhal Number (St):

\[
St = 0.198 \left(1 - \frac{19.7}{Re}\right) = 0.198 \left(1 - \frac{19.7}{28539.32}\right)
\]

\[
St = 0.1978
\]

3. Vortex Shedding Frequency (fv):

\[
f_v = \frac{St U}{D} = 0.1978 \times 1 / 25.4 \times 10^{-3}
\]

\[
f_v = 7.787 \text{ Hz}
\]

4. Lift force (F_L):

\[
F_L = 0.5 \times \rho_{\text{fluid}} LD^2 \times C_L = 0.5 \times 998 \times 200 \times e^{-3} \times 25.4e^{-3} \times 1^2 \times 0.8
\]

\[
F_L = 2.027 \text{ N}
\]

Coefficient of lift \( CL \) is assumed 0.8 as a conservative estimate based on background research. Realistically, \( CL \) varies with displacement of the cylinder, so this value is an average.

5. Apparent mass (mapp):

\[
Vol = \frac{\pi}{4} (D^2 \times L) = \frac{\pi}{4} ((25.4 \times 10^{-3})^2 \times (200 \times 10^{-3})) = 1.0134 \times 10^{-4} \text{ m}^3
\]

\[
m_{\text{dis}} = \rho_{\text{fluid}} \times Vol = 998 \times 1.0134 \times 10^{-4} = 0.10114 \text{ kg}
\]

\[
m_{\text{add}} = 0 \text{ kg}
\]

\[
m_{\text{pipe}} = (\rho_{\text{cyl}} \times L) + m_{\text{add}} = (0.64 \times 200 \times 10^{-3}) + 0 = 0.128 \text{ kg}
\]

\[
m_{\text{app}} = m_{\text{pipe}} + m_{\text{dis}} = 0.22914 \text{ kg}
\]
Where Vol is Volume of the cylinder, \( m_{\text{dis}} \) is mass of fluid displaced by the cylinder, \( \rho_{\text{fluid}} \) is water density, mass \( m_{\text{add}} \) represents additional mass added to the pipe, which will initially be set as 0. The pipe mass \( m_{\text{pipe}} \) was determined based on unit length density \( (\rho_{\text{cyl}}) \) of 0.64kg/m.

6. Spring Stiffness (k):

\[
k = (2\pi f_p)^2 \times m_{\text{ap}} = (2 \times \pi \times 7.787)^2 \times 0.22914 = 548.53 \text{ kg/m} = 548.53 \times 9.81
\]

\[
k = 5381.09 \text{ N/m}
\]

vi. CFD Simulation: The turbulent analysis is used in the CFD simulation as the Reynolds number is in turbulent region. K-omega (due to transient flow) type of turbulence model is chosen. In Figure 4, the displacement history of the freely vibrating cylinder at Re = 100 is shown. The simulation is conducted for 6 second flow time. The vertical axis indicates the lift force in Newton and the horizontal axis is the flow duration in second. From the figure, it can be seen that the cylinder response rises after a second. Between the time value of 1 second to 2.5 seconds, the lift force is constantly rising. After 2.5 seconds, the lift force is constant and measures around 4N.

8. Conclusions:

- Through mathematical calculations, CFD modelling and small-scale experiments, the potential for vortex-induced vibrations as an energy source was studied.
- Based on the background research, mathematical calculations were done in order to predict the relationship between experimental parameters and cylinder response.
- Based on the mathematical calculations, CFD modelling was done to obtain few key parameters involved to establish feasibility of small scale VIV testing and to create estimates for experimental results.
- Overall, this project demonstrated the power generation at small scale. The output DC Voltage obtained lights up the LED in our case. Therefore, there is a potential for vortex-induced vibrations as a source of energy generation.
• The consequences of conventional hydropower due to damming of water, changed water flow and the construction of roads and power lines are detrimental to aquatic ecosystem. We as engineers are developing an energy harvester without unbalancing the aquatic ecosystem.

• Billions of watts of power continuously flow down rivers and streams, or wash up on shores, just to dissipate. It is also immensely challenging to exploit. We as engineers are trying to tap this vast, restless resource to create sustainable energy that competes with fossil fuels and is compatible with existing power grids.

• India, being a Growth engine, plays a crucial role in the world energy trends. There has been a steady growth in the electricity production in India. Our energy harvester can applied in power generation of Clean Energy and using it to satisfy the energy needs of the society.

9. Scope for Future Work:

• Increasing the Reynolds number by increasing fluid velocity and increasing cylinder diameter by a few inches would allow for results that could more accurately predict the potential for the technology under realistic conditions

• For large scale, where flow speeds are significantly high, piezoelectric material can be used for mast. As load increases on mast, stress will be induced in piezoelectric material thereby producing electricity more efficiently.

• AC generators can be used in case of high flow speeds. At low flow speeds, AC generators are not feasible as some energy generated will be wasted for the conversion of direct current to alternating current. But when velocity increases, load on mast also increases and use of AC generator is feasible.

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