Numerical Analysis of Solar Roadways using ANSYS

A. Hemamathi, M. Uscharani, Seena Simon, I. Lavanya, M. Raja Rajeshwari

Abstract: Today there are more consequences in climate change due to over utilization of fossil fuels thus leading to serious impact on environment. So there is a need for an alternative solution to reduce the consumption of such non-renewable resources. One such effort made in the field of Highway is the development of “Solar Roadways” which can be an alternative solution. Solar roads combine different solution in one – it can help us to improve the production of electricity using solar panels, to provide a digital platform for our future nation’s projects like Smart Cities and to facilitate the emerging electric cars that replaces the petrol driven vehicles and much more. This approach through this paper can offer many additional benefits to the people, environment and will contribute for the sustainable development to a larger extent. A rural road incorporating solar panels has been fabricated and a finite element analysis of the model of pavement is done using ANSYS software and loads for rural roads are applied as per IRC standards. Parameters such as stress, strain and deformation are investigated and it is found that the results are well within the permissible limits.

Keywords: Smart Grid, Ansys, Arduino, Piezoelectric sensor, Load cell.

I. INTRODUCTION

The Earth’s climate has changed over history. Just in 650,000 years there has been a seven cycles of glacial advance and retreat since the last ice age that ended in around 7000 years ago. This abrupt situation around the world is due to increase in temperature. Nowadays, climatic change has been showing diverse effects in economy, health and communities in many ways. Scientist have warned that disastrous situation will take place in the coming years if this issue is not taken into serious concerns; hence various methods should be adopted in various fields to overcome the climate change taking place all around the world. Hence a technology is being introduction in the field of roadways that meets the energy production and also is implemented with good traffic assistance to reduce road accidents all over the world.

During 2015, a particularly bad year for our country the heat waves killed around 2000 Indians and at the month of December Chennai has faced a disastrous flood killing many lives and severe damage to the property. These effects are simply due to nothing but a simple phenomenon called all over the world is nothing but climatic change that leads to rise in temperature on the Earth’s surface. The cause for such change in India is due to increased population explosion and continuous carbon emission due to emergency of numerous industries in our country. A rise of around 2.25°C took place at the particular year across South Asia, including India says an International study published in the year 2016. And the situation continues year by year with an increase in temperature of 10° F a global temperature rises all over the world, including India.

A. Anti – Global Warming Measures: In concerns with these activities the two major industries that are the key to global warming are – vehicular emission and energy production (India’s major energy production is from the Thermal Power Plants). Thus, measures are to be aken to reduce the impact from the above two sectors by reducing the pollution. It can be done by increasing the usage of renewable resource like sun, wind, hydro power etc. in spite of usage from nonrenewable resources like coal there by cut down the emission of these gases to half.

B. Traffic Characteristics of India: India, is not among the countries cause for increase in global temperature but also road accidents are increasing year by year according to the current road statistics. In the year of 2015, there was about 5 lakh road accidents in India killing around 1.5 lakh people and about 5 lakh people got injured as per the survey taken. And it is being said that the increase in 2% of road network in India year by year has literally been increasing the level of road accidents to about 28% as per the recent studies.
Numerical analysis of solar roadways using ANSYS

II. SOLAR ROADWAYS

As per the Bill passed by the Indian Government, Smart cities are to be established all over the country. Solar Roadways is a company based started by Scott and Julie Brusaw in the early 2009 in U.S. This idea can be implemented in the Smart city in our country where the Asphalt based roads with structurally – engineered solar panel. Roads are built in such a way that they can illuminate themselves and are provided with intelligent traffic assistance to reduce the road accidents and help the driver to ride safely. Consumption of non – renewable resource for power production can be reduced in place if solar panels are used where directly electricity can be generated from the roads without the usage of grids. Therefore, initially idea can be developed by just placing the solar panel on the road and provide intelligent traffic assistance and it can be extended further by connecting IoT based technology along with it.

The layers of Solar Roadways are:

1. Road Surface Layer
2. Electronic Layer
3. Base plate Layer

i. Road Surface Layer: Translucent and high-strength glass, it is rough enough to provide sufficient traction, yet still passes sunlight through to the solar collector cells embedded within, along with LEDs and a heating element. This layer needs to be capable of handling today’s heaviest loads under the worst of conditions and to be weatherproof, to protect the electronics layer beneath it. Solar Road Panels are made of tempered glass.

ii. Electronic Layer: The electronic layer used in the model consists of several components:

i. Solar panel 10V
ii. Arduino UNO board
iii. TP4056 charge controller
iv. Boost converter
v. Piezoelectric sensor
vi. LCD 16*2 display
vii. Piezoelectric load cell
viii. Street lights

Fig 2 Block Diagram of Electronic layer

1. Solar Panel 10V: Solar panel work on photovoltaic effect where the light captured from the sun is converted into electricity. The solar panel used in the model has 10 V capacity. The dimensions of solar panel are 8.0 cm x 3.5 cm, 10 panels are interlinked and placed one after another.

2. Arduino UNO Board: Arduino Uno a microcontroller board is based on 8-bit ATmega328P microcontroller. Along with ATmega328P, it consists of other components they are crystal oscillator, serial communication, voltage regulator, etc. to support the microcontroller. Arduino Uno has 14 digital input/output pins (out of which 6 can be used as PWM outputs), 6 analog input pins, USB connection, Power barrel jack, ICSP header and reset button. It has analog to digital converter.

3. TP4056 Charge Controller: The TP4056 a complete constant-current/voltage linear charger for single cell lithium-ion batteries. Its SOP package and low external component count make the TP4056 ideally suited for portable applications. Furthermore, the TP4056 can work within USB and wall adapter. No blocking diode is required due to the internal PMOSFET architecture and have to prevent negative Charge Current Circuit. Thermal feedback regulates the charge current to limit the die temperature during high power operation or high ambient temperature. The charge voltage is fixed at 4.2V, and the charge current can be programmed externally with a single resistor. The TP4056 automatically terminates the charge cycle when the charge current drops to 1/10th the programmed value after the final float voltage is reached.

4. Boost Converter: A boost converter (step-up converter) is a DC-to-DC power converter that steps up voltage (while stepping down current) from its input (supply) to its output (load). It is a class of switched – mode power supply (SMPS) containing at least two semiconductors (a diode and a transistor) and at least one energy storage element: a capacitor, inductor, or the two in combination. To reduce voltage ripple, filters made of capacitors (sometimes in combination with inductors) is normally added to such a converter's output (load-side filter) and input (supply-side filter).

5. Piezoelectric sensor: The piezoelectric sensor is a device used to the piezoelectric effect. This sensor measures the change of pressure, force, temperature, strain and acceleration. Piezoelectric effect is converted into an electrical charge. When any obstacles touch the sensor it is displayed on the LCD as “Obstacle Detected GO SLOW”.

Fig 1. Share of Road Network Vs Road Accident in 2015.
6. **LCD 16x2 Display**: Liquid Crystal Display is an electronic module and finds wide range of application. The LCD 16x2 is the widely used screen size to display data. Here it displays the output from the Arduino, which is connected to the piezoelectric load cell and piezoelectric sensor and also the voltage output from the solar panels.

7. **Piezoelectric load cell**: Piezoelectric load cells work on the principle of deformation as the strain gauge load cells, but a voltage output is generated by the basic piezoelectric material - proportional to the deformation of load cell. Here in model, in the place of load cell piezoelectric sensor is used where pressure limit is set in terms of weight. If a load of pressure having an analog value above 60 is sensed by the sensor it is displayed as “Over Weight” on the LCD. In real time load cell is placed below the load surface which is set with a load limit and detects load that goes above it.

III. FEATURES OF SOLAR ROADWAY

The following are the features of solar roadway:

i. Illuminated roads

ii. On the go charging

iii. Traffic Assistance

iv. Smart Grid

A. **Illuminated Roads**: LEDs are embedded in the electronic layer directly and they are set in a way to display signals on the surface of the road that ensures safe driving during night time.

B. **On the go Charging**: Electric cars are provided with induction plate that enables to charge the vehicle while moving on the surface itself. In some cases, charging bays are provided that helps to charge the vehicle.

C. **Traffic Assistance**: LEDs enable to transfer messages on the surface of the road itself that alerts the driver and controls accident rate. Load cell placed below the road surface alerts the driver if there is any sudden change of load on the surface.

D. **Smart Grid**: Removes the need for power grid, overhead cables and wires due to network congestion occurring due to the transmission of electricity, cost of transmission towers are reduced.

IV. CONTROVERSIES

The following are the controversies of solar roads:

i. Road Safety
Numerical analysis of solar roadways using ANSYS

ii. Road Durability

iii. Initial cost

A. Road Safety: Driving or walking on texture glass, is different from asphalt roads and hence it is subjected to more test.

B. Road Durability: Durability is proven by only by 3D modelling analysis. Hence additional durability should be done on the panel.

C. Initial Cost: One sq.ft. 12 x 12 = 144 sq.ft.

One panel cost $6912

Cost per sq.ft. = $48 1$ = 68.93 INR

Hence cost of solar road per square feet is around Rs.3300 which is three times more that Asphalt road.

V. INDIAN ROAD NETWORK

Indian road network comprises 1.7% national highway and 5 % of state highway. If Asphalt roads are replaced by Solar roadways it will produce around 450TWh electricity. But India needs about 910TWh electricity. So, if 10% of the roads are replaced by solar panels it will meet the electricity need of the country.

VI. ASPHALT ROADS Vs SOLAR ROADWAYS

Table 1 Asphalt Road Vs Solar Roadways

<table>
<thead>
<tr>
<th>ASPHALT ROAD</th>
<th>SOLAR ROADWAYS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial cost is Rs.1102 for Asphalt roads</td>
<td>Initial cost is three times than that of Asphalt roads</td>
</tr>
<tr>
<td>Cost of Asphalt increases when petroleum cost increases</td>
<td>No such issues occurs here.</td>
</tr>
<tr>
<td>Initial cost is low, but maintenance cost is high.</td>
<td>Initial cost is high, but maintenance cost is low.</td>
</tr>
<tr>
<td>Last for 7 years</td>
<td>Last for 21 years</td>
</tr>
</tbody>
</table>

VII. DESIGN OF RURAL ROADS

The pavement is designed for low volume rural road as per IRC SP 20:2002(Rural roads Manual)

A. Design Parameters (Assumed):

\[ P - \text{Number of commercial vehicles as per last count} = 198 \ CVPD \]
\[ r - \text{Traffic growth rate} = 6\% \ (\text{according to code}) \]
\[ n - \text{Years between the traffic count and completion of construction} = 0 \text{ years} \]
\[ x - \text{Design Life} = 10 \text{ years} \]

\[ A = 198(1+0.06)^{10} =198(1.06)^{10} \]
\[ A = 198(1.7908) = 354 \ CVPD. \]

Total Thickness = 470 mm

Table 2 Thickness of Individual layers

<table>
<thead>
<tr>
<th>Layer of Pavement</th>
<th>Provision made</th>
<th>Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subgrade</td>
<td>Existing natural subgrade</td>
<td>-</td>
</tr>
<tr>
<td>Sub – Base</td>
<td>Granular Sub – Base</td>
<td>300</td>
</tr>
<tr>
<td>Base</td>
<td>Wet Mix Macadam</td>
<td>150</td>
</tr>
<tr>
<td>Wearing Course</td>
<td>SDBC</td>
<td>20</td>
</tr>
</tbody>
</table>

VIII. PAVEMENT ANALYSIS

The pavement was analyzed using finite element software ANSYS to validate the deflection of pavement for various vehicular loading condition. To differentiate the different layers the surface layer was divided into 5 divisions, base layer 10 divisions and sub grade into 15 divisions. Two wheeler, three wheeler and four wheeler loads were applied as concentrated loads on the pavement and the behavior of stresses was studied. The following properties were assigned to different layers of the pavement.

Considering width of road = 5m

Table 3 Properties of individual layers

<table>
<thead>
<tr>
<th>layers</th>
<th>Modulus of Elasticity (Pa)</th>
<th>Poisson’s ratio</th>
<th>Density (Kg/m^3)</th>
<th>Thickness (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface layer</td>
<td>33E6</td>
<td>0.27</td>
<td>1190</td>
<td>0.09</td>
</tr>
<tr>
<td>Base Layer</td>
<td>23E6</td>
<td>0.49</td>
<td>1430</td>
<td>0.25</td>
</tr>
<tr>
<td>Subgrade</td>
<td>10E6</td>
<td>0.45</td>
<td>1690</td>
<td>\infty</td>
</tr>
</tbody>
</table>

A. Application of load

As the design is for rural roads two wheeler and three wheeler loads are applied at the nodes.

For Two Wheeler = 1500 N (downwards)
For Three wheeler = 5500 N (downwards)
### B. Results

Results of stress, strain and deformation are shown in figures below:

1. A Fabricated model is made, and sensors are connected to the Arduino to find the load acting on the surface of the pavement and obstacle detection is done.
2. The sensor was able to sense for any obstruction on the pavement alerting the driver by passing signals through the sensors.
3. The sensor also gives an alerting signal when the pavement is overloaded. This protects the solar panels from getting damaged.
4. The ANSYS results has shown that the stresses and strain on the pavement are within the permissible limits, protecting the pavement from getting damaged for the given loading condition.

### REFERENCES:

5. Aaron Seward(2014)” Best of whats new: solar roadways”

### AUTHORS PROFILE

**A.Hemamathi**, working as Assistant professor at RMK Engineering College has obtained her B.E. (Civil) from Thiagarajar college of Engineering, M.E (Structural Engineering) from Regional Engineering college, Trichirapalli and currently pursuing her Ph.D at Anna University, Chennai. Her area of interests includes but not limited to precast concrete connection, earthquake engineering, design of RC structures. She is a Life member of ISTE , ICI. & IEI.

**Dr.M.Usharani** working as a professor at RMK Engineering College, obtained her B.E. (Civil) M.E. (Structural Engineering) and Ph.D (Structural Engineering) all the three from Coimbatore Institute of Technology, Coimbatore. She has about 23 years of experience in teaching for U.G & P.G and 9 years of experience in construction industry. Totally She has Published 30 Research Papers in International journals, National journals, International and National Conferences. She has authored two books on Structural Analysis I & II. She is a Life member of ISTE , ICI. & IEI.
Numerical analysis of solar roadways using ANSYS

Seena Simon working as Assistant Professor in R. M. K. Engineering College, Kavaraipettai. Completed B.Tech in Civil Engineering from Calicut University in 2009. Completed M.E in Structural Engineering from Anna University in 2012. She is a life member of ISTE.

I.Lavanya is an undergraduate student of Civil Engineering, R.M.K Engineering college. Her area of interest includes structural engineering and application of software in civil Engineering. She is a student member of ISTE, ICI, & IEI

M.Raja Rajeshwari is an undergraduate student of Civil Engineering, R.M.K Engineering college. Her area of interest includes structural engineering and application of software in civil Engineering. She is a student member of ISTE, ICI, & IEI.