Antenna Deployment Mechanism for a 3U CubeSat Project

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Abstract. There is an ever-increasing requirement for smaller and more efficient satellites. Minimizing the size of satellites has its advantages. It equally imposes several challenges in bringing up the satellite from the drawing board to a flight model. This paper focuses on an antenna deployment mechanism that is being developed by a student satellite team from BMS college of engineering. Antenna deployment mechanisms of similar class satellite programs were referred and a model has been developed and analyzed. Experiments were also conducted on a prototype model to verify the conceptual working of the mechanism.

Keywords: 3U CubeSat · Antenna deployment mechanism · Experiments on antenna deployment.

1 Introduction

BMSCE Upagraha is a 3U student satellite project currently under development by the students of B.M.S College of Engineering. The BMSCE Upagraha has an RGB imaging camera as its payload, and for the communication of the satellite to the ground station, it makes use of two dipole antennas. The antenna plays an integral role in establishing proper communication between the satellite and the ground station. Due to restrictions in the fairing volume, antennas are stowed in the spacecraft body during launch and are deployed in space. Hence, deployment of the antenna adhering to its functional requirements is a crucial phase in the satellite operation. This paper focuses on the development of the antenna deployment mechanism. A conceptual model is designed according to the design criteria established. A prototype model has been fabricated to verify the working of the deployment mechanism. Also mentioned in this paper are – The description of the selected system, design considerations, structural analysis, and experiments carried out to verify the concept. Details of activities to be carried out are also given in this paper.

2 Functional Requirements

It is very much necessary for the mechanism to fulfill the basic requirements throughout the flight period.
– The basic requirement is to keep the antenna in stowed condition during launch and deploy them in orbit.
– 2 dipole antennas are to be deployed, they are the UHF (Ultra high frequency) and VHF (Very high frequency) antennas. Their specifications are as follows
– For Up-link Receiver (VHF):
Operating frequency = 145MHz
Length(L) = 0.48* λ = 1m
where λ is the wavelength of the transmission
– For Downlink Receiver (UHF):
Operating frequency = 437MHz
Length(L) = 0.48* λ = 0.33m
– Angle of deployment of each antenna should be 90 degrees.
– Launch vehicle considered is PSLV. The levels identified are as per the PSLV user manual.
– Stowed natural frequency should be greater than 135 Hz, and a deployed The natural frequency of 2Hz (TBD).
– Quasi-static loads requirements are: Longitudinal load-7g compression, 3.5g tension and Lateral load-+/- 2g.
– Provision should be through telemetry to monitor the hold-down release and deployment function.

3 Options Study

A study was conducted on some of the previously used deployment mechanisms In different satellites. Fig 1 depicts the different satellites and their deployment mechanisms studied for the option studies.

(a) *UCAELFIN [4]* *(b) SAMSAT-218D [3]* *(c) XATCOBEO [1]* *(d) BIRDS 2 CUBESAT [2]*

Fig 1: Options study performed

Table 1 provides the details of these mechanisms and their disadvantages:

Table 1: Option studies performed. [1][2][3][4]

Sl no.	Factors	Tuna-can deployment mechanism	Fusible element mechanism	Polymeric 3D printed Antenna deployment mechanism	Heat wire release mechanism
1	Components used for retention	Fishing line	Soldered alloy & Gate	Nylon thread	Dyneema/Vectran
2	Length of the antenna that can be deployed	450-500 mm	300-500 mm	300-500 mm	Around 500 mm
3	Configuration or orientation	45 degrees to the top panel	Parallel to the top panel	Parallel to the top panel	Parallel to the top panel
4	Functioning	Requires two main parts, individual antenna holders and the tuna can. Once command is provided a single burn resistor cuts the retention wire and antennae deploys simultaneously. [4]	No burning mechanism involved. Requires a cradle to hold the antenna, uses a heating element and gate. The heating element melts the soldering, hence deploying the antenna. [3]	Antennae are coiled on the extremity of the setup. A single burn mechanism releases all the stowed antennae. [1]	Antenna is held down around the mounting screws in the stowed position. One side of the antenna is screwed to the secure part. The free end is tied with a Dyneema / Vectran cable connected to nichrome wire of the burner circuit. [2]
5	Heritage	Used in UCAELFIN Satellite [4]	Has been used in SamSat-218D 3U CubeSat [3]	Used in XATCOBEO [1]	Used in BIRDS-2 CUBESAT [2]

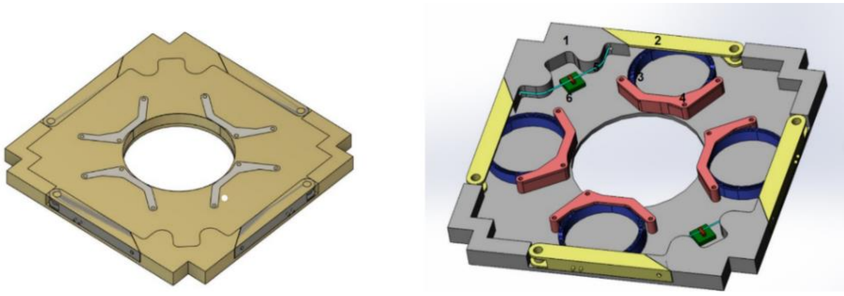
6	Disad-vantages	(i) The height of this mechanism is 13.5 mm, and this should be the minimum clearance on the top panel of the spacecraft. (ii)Does not meet the angle of deployment requirement.	(i)Heritage of this mechanism shows that this mechanism has failed to deploy. (ii)Since it uses a soldered element as a retention mechanism a standard soldering procedure and soldering skill is required while operating and testing.	(i)Outgassing and ESD risks of the sub-chassis are more. (ii)The materials used for most of the components are out of the ordinary which gives us less information to work with.	(i)Overheating of nichrome wire. (ii)Would require considerably higher power.

Considering the pros and cons of all the above-mentioned mechanisms, a new mechanism has been developed which abides by the design criteria. This newly developed mechanism is discussed in detail below.

4 System Description

Based on the options study performed and the functional and identified antenna requirements, a conceptual model was developed and the details are as follows:
– Lever: 25-gauge stainless steel sheet metal
– Antenna: A 32-gauge Stainless steel tape measure
(Dimensions: 500mm X 12mm X 0.2 mm)
– Hold down wire: Nylon thread

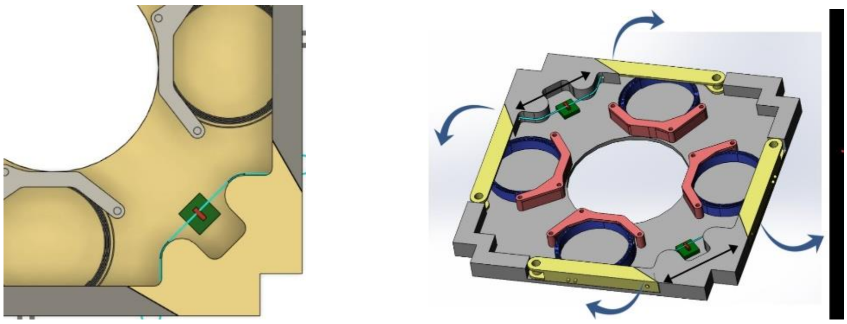
1. Base plate
2. Lever
3. Antenna
4. Antenna holder/housing
5. Hold down wire
6. Burn resistor or heating element



(a) *3D model of Deployment mechanism* *(b) Detailed view of the deployment mechanism*

Fig 2: Views of the antenna deployment mechanism

The Base plate holds the complete mechanism for deploying 4 antennas (2 dipole antennas). In the stowed condition as shown in Fig2 the lever is closed which holds the antenna in a coiled form i.e, in the stowed position. The antenna holder/housing helps in giving the circular shape in this stowed condition. One end of the lever is held with a pivoted joint, with the help of an internally threaded fastener and an external smooth surface, which allows the lever to rotate about this joint. The other end is tied to the hold-down wire which is in turn attached to the adjacent lever similarly. A burn resistor is set up in between two adjacent levers.



(a) Hold down wire connected to 2 adjacent levers *(b) Deployment directions*

Fig 3: Hold down details and deployment direction

This burn resistor is placed in such a way that the hold-down wire is in contact with the burn resistor. A command is then executed by the telemetry, tracking and command team, so that the burn resistor is activated and current passes through it. The temperature of the burn resistor increases, once the temperature of the burn resistor is greater than the melting point of the hold down wire, the hold down wire is cut and the internally stored energy of the coiled antenna pushes the lever making it rotate about the pivot joint. Thereby the antenna uncoils and straightens itself. Fig3b shows the deployment directions of the lever, as the current is passed through the burn resistor, the wire is cut and the internally stored energy of the coiled antenna pushes the lever and the antenna uncoils itself into a stiffened antenna.

Fig4 represents the deployed state of the antenna, where two long antennae represent 2 VHF (Very high frequency) antennas and 2 short antennas represent UHF (Ultra high frequency) antennas.

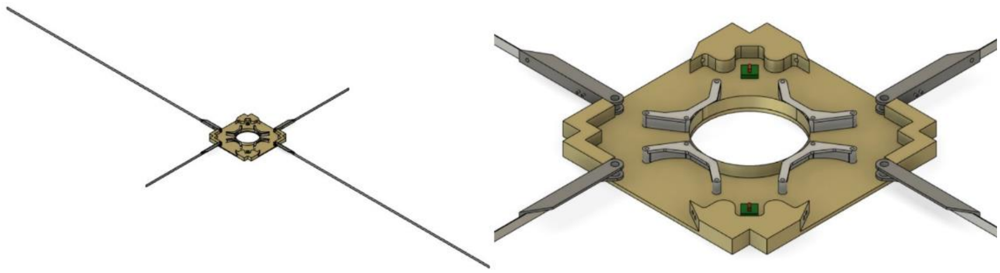


Fig 4: Deployed view of the mechanism

5 Design Considerations

- Both the UHF and VHF antennas will be divided into 2 monopoles, each of length of 0.5m for the VHF band and 0.17m for the UHF band.
- The dimensions of the top panel are 100*100 mm2, and a cutout of 8.5*8.5mm2 has to be made on each corner of the satellite's top surface to include the rail rod.
- The maximum available diameter for the coiling of the antenna in the stowed condition is 25mm.
- The angle of deployment of each of the antennas is 90 degrees.
- Tension in the hold-down wire has to be designed to withstand the launch loads.
- The deployment process of the mechanism is by a single-point release on command.
- Deployed latch-up shock should be within acceptable limits.
- The mechanism should operate in the temperature range of -30 to +80 degrees Celsius and under low earth orbit (LEO) vacuum conditions.
- The material used must have a good flight heritage and must be compatible with the space environment.
- The design should meet the stowed and deployed natural frequencies of the antenna and the launch loads as mentioned in the functional requirements.

6 Experiment Conducted

As explained in the system description, after arriving at the basic configuration, a prototype model was realized with available materials. Initial trials were conducted to see the deployment. It was observed that the lever which was manually made out of sheet metal was flexible. This was modified by fabricating it out of a stainless-steel block of size 47X10X8 mm. The hold down and release mechanism was actuated by manually cutting the wire instead of using the burn wire mechanism.

The parts were assembled on a base plate and deployment trials were conducted. A measuring tape was used to depict the antenna. A coil radius of 25 mm was given to it and the deployment was conducted. Certain observations were made:
– It was observed that the antenna during deployment was not deploying smoothly, instead, it used to go back and forth in a whiplash fashion and significant oscillations were observed about the deployment axis. (This phenomenon was found by conducting another test and monitoring the same with the help of a high-speed camera. When the captured data was replayed, it was clearly seen that the deployment was not smooth and the antenna deployed with a whiplash phenomenon.)

To overcome the drawbacks observed in the previous model. A Detailed fabrication of the deployment components was done. A high-speed camera was used to capture footage in slow motion. The mass of the lever was slightly increased and the width of the antenna was reduced to avoid whiplash.

The new experimental model consists of the following
1. Base plate- It was made out of stainless steel material to obtain sufficient rigidity. It houses the other components.
2. Lever which was earlier fabricated by a sheet metal is now modified to Stainless steel. It was fabricated by EDM machining.
3. Antenna housing - ABS (Acrylonitrile Butadiene Styrene) material. This The component was 3D printed.
4. The antenna - A 32-gauge Stainless steel measuring tape (Dimensions: 500mmX 4mm X 0.2 mm) whose width earlier was 12 mm is now reduced to 4mm.

After monitoring the modification one more test was conducted and the problems encountered in the earlier test were not seen. The process of the deployment was recorded again using a high-speed camera. Several trials of the deployment were recorded and later analyzed using the 'Tracker' software. It is video analysis and modeling tool. The slow-motion video was uploaded into the software and calibrated accurately for every test.

Fig5 shows the tracking of points of a specified location on the lever with respect to an origin during the deployment.

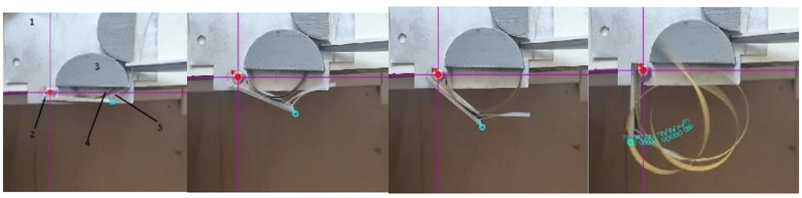


Fig 5: Tracking of the deployed lever

The origin is set on the axis of rotation of the lever. (shown in pink color) The points which are tracked are depicted as cyan diamond markers. The movement of the lever while being deployed is noted and marked at every frame and this path is followed. The software analyzes the movement of the lever, calculating its instantaneous position at every frame with respect to the origin.

A graph of angular velocity (ω) vs time (t) is plotted. Linear curve fitting is done to obtain a best fit straight line for the obtained set of points. By finding the slope of this best fit line, we will have the angular acceleration (a) with which the lever deploys.

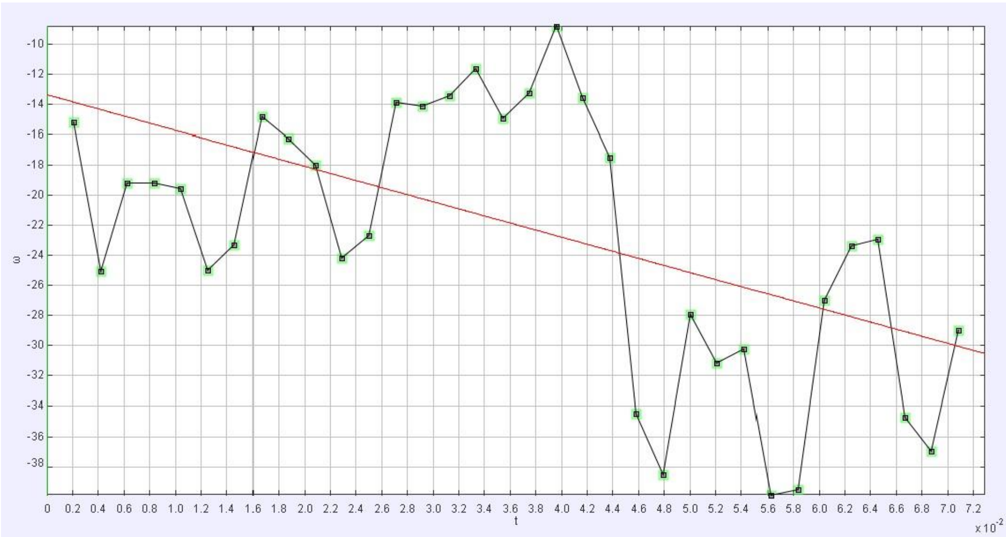


Fig 6: Graph of ω vs t

$$T = I * a \quad (1)$$

Where,

T- Torque or turning moment experienced by the lever …(N-m)

I -Moment of inertia about rotating axis of the lever …(Kg-m2)

a- Angular acceleration of the lever …(rad/s2)

Slope of the best fit line from Fig 6 is, (a) = 239 rad/s2

The moment of inertia of the lever is found to be I = 4578.23 e−9 Kg−m2

(This was obtained by finding the mass of the lever and this mass is used as an input to a CAD software from which we obtain the moment of inertia about the rotational axis.)

$$T = I * a = 239 * 4578.23e{-9} = 1.094 N - mm$$

This value of torque is used as an input in the analysis phase, where a turning moment is given to the internal surface of the lever which would be in contact with the antenna.

7 Analysis carried out on the antenna deployment lever in the stowed configuration

The types of analysis performed on the lever of the antenna deployment mechanism are:
– Quasi-static acceleration
– Prestress modal
– Random vibration

The load values for all the analysis is taken from the PSLV launch load data.
Loads and stiffness for the CubeSat are as follows:
– Longitudinal load: 7g compression, 3.5g tension
– Longitudinal stiffness: >135Hz
– Lateral load: +/- 2g
– Lateral stiffness: >70Hz
– Qualification factor: 1.25

This analysis aims to find the
– Stresses developed in the lever
– Initial modes of vibration
– The reaction forces developed at those places where the hold down wire will be in contact with the lever. (These reaction forces depict the tension under which the hold down wire will be subjected to.)

The static structural analysis accommodates the quasi-static acceleration loads and this is set as a precursor to the modal analysis, where we get an estimate of the natural frequencies of the setup. This analysis is only helpful in finding the stresses developed on the lever alone and not the antenna as the analysis does not completely qualify the conceptual model as only the lever of the antenna is modeled and the coiled antenna itself is not modeled. The natural frequency of the overall setup is yet to be found. (Analysis description is shown in Fig7.)

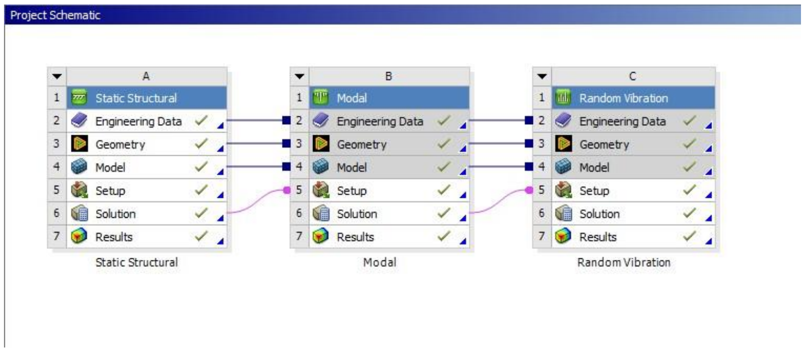


Fig 7: Analysis description

7.1 Geometry

The model for the analysis comprises 3 components (as shown in Fig 8):
1. Base
2. Lever
3. Through hole fastener

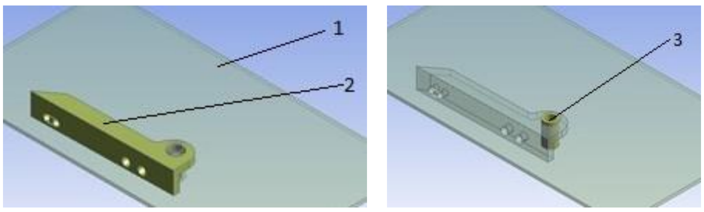


Fig 8: Depiction of geometries

The lever rotates about the axis of the through hole fastener and is in contact with the external surface of the fastener. The fastener is threaded inside but has a smooth exterior. The base supports both the lever and the fastener. To simplify the geometry and to decrease the computing time, a single lever setup is considered instead of the entire 4 lever assembly. Fig 9 represents the depiction of meshed geometries.

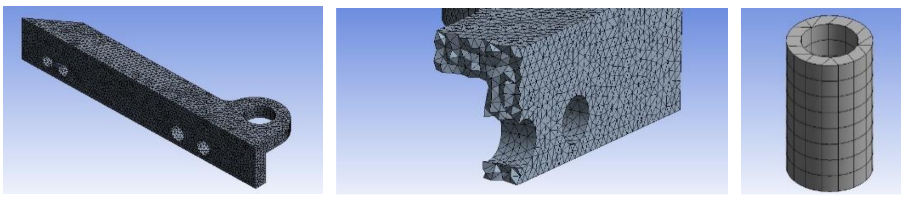


Fig 9: Depiction of meshed geometries

7.2 Boundary Conditions

1. Fixed support: the surface of the lever which will be in contact with the hold-down wire is given a fixed support.
2. Moment: A moment of 0.2 N-m is given to the entire surface of the lever which will be in contact with the antenna.
3. Remote displacement: A remote displacement is given to that surface which will be in contact with the through hole fastener. To simulate the deployment direction, linear movement of the lever in X, Y, and Z direction are constrained and it is allowed to rotate about the axes.
4. Fixed support 2: The threaded or the inner surface of the fastener is given a fixed support since this is the area that will be completely fixed and will not move with respect to the base.

Fig 10 depicts the different boundary conditions applied to the meshed geometries.

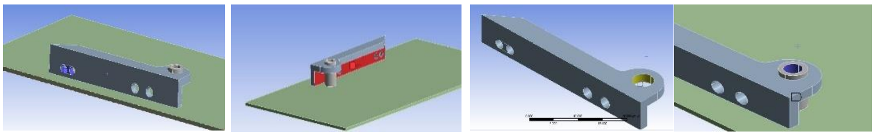


Fig 10: Boundary conditions

7.3 Results

Quasi-static acceleration

1. Equivalent stresses (Von-mises stress):
   A maximum stress of 2.79MPa is observed at the edges where the hold-down wire is tied to the lever. This depicts that the location where the hold-down wire is attached to the lever is the location of maximum stress concentration under acceleration loads as shown in Fig 11(a).

2. Reaction force:
   The total reaction force observed at this support is 6.09N i.e., during the application of acceleration loads, the tension in the hold down wire due to this lever would be around 6.09N as depicted in Fig 11(b).

Prestressed modal results

The first 6 modes of natural frequencies of the lever-fastener-base assembly are presented below.

Table 2: First 6 modes of vibration

Mode	Frequency (Hz)
1	1211.9
2	2553.9
3	4277.2
4	16462
5	19834
6	21688

Random vibration

1. Equivalent stresses (Von-mises stress): Maximum stress of 10.2MPa is observed at the bottom face edge of the lever. This may be because this face of the lever will be in contact with the base and due to excitation of the vibrational loads the lever will strike the base plate. This is depicted in Fig 11(c).
2. Reaction force: A maximum reaction force of 8.27 N is observed at the hold-down support of the lever faces.

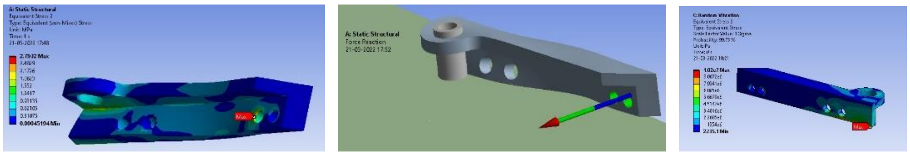


Fig 11: Depiction of results

Summary of the analysis performed

- Stresses developed due to the acceleration loads are within acceptable limits.
- The stiffness requirements are met.
- Stresses developed due to random vibration loads are within acceptable limits.
- The reaction forces observed due to the acceleration and random vibration loads would be used for the design of the hold-down system.
- The design of the lever has been decided to be modified so that the bottom face of the lever would not be in contact with the base plate. This is done to reduce the frictional forces in play during deployment.

8 Planned activities

- Detailed design of the hold down and release mechanism, as well as the deployment mechanism, are to be performed. To provide sufficient stiffness to the antenna, the cross-section of the antenna has to be suitably designed (preferably by providing a curvature) to meet the deployed stiffness requirements.
- Detailed analysis to establish the stowed and deployed natural frequencies and any latch-up shock arising after deployment.
- Fabrication of the different parts is planned to be carried out using CNC machines. After fabricating the antenna, it has to be suitably heat treated. Beryllium copper was found to be a suitable candidate material for this purpose.
- After the prototype model is completed, an engineering model will be developed followed by a flight model.
- Functional tests will be carried out to demonstrate the capabilities of the hold-down release and deployment mechanism. The developed deployment mechanism would be integrated into the satellite structure along with the other components. The assembled satellite structure would be subjected to different environmental tests such as - The Vibration test, Shock test, and Thermovac test.

9 Conclusion

The BMSCE Upagraha which is a 3U satellite makes use of 2 dipole UHF and VHF antennas. These antennas are in stowed condition during launch and later they are deployed in space by ground command. The mechanism being developed will have a hold down and release mechanism to keep the antenna in stowed condition during launch and a deployment mechanism to positively release the antenna in orbit.

Briefed in this paper are activities carried out for the development of a hold-down release and antenna deployment mechanism. This includes the option studies performed on existing antenna deployment mechanisms, description of the selected and designed system, design considerations, experiments, and the analysis carried out so far, and also includes the plan for future activities. The results obtained from the initial structural analysis qualify the designed deployment mechanism. Further, the results obtained from this analysis will be used for the detailed design of the mechanism. The option studies performed and the results obtained in this paper will hence be a good platform for the development of the intended deployment mechanism and also for other emerging strategies in this field.

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