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Numerical Analysis for Solar Panel Subjected with an External Force to Overcome Adhesive Force in Desert Areas

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ABSTRACT

The dust accumulation is an undesirable phenomenon in a solar plant environment. The dust removing procedures were using traditional techniques which are led to more loss in power especially in desert areas. Additionally, most of the cleaning techniques are designed according to the concept of vanquishing the adhesive force of dust particles by adding a harmonic excitation force. This force may produce damage to the solar panel. Therefore, the main objective of the current study is to simulate a traditional solar panel model BSP32-10 with ANSYS software throw an additional external force (2, 4, 6, 10, and 15 Newton) throws six mode shapes and verified experimentally. Deformation values of solar panel surface increase with an increase in excitation force, and not exceed the natural frequency deformation, with average values from 0.07 to 1.5 mm, while 94% of these results are close to experimental work during verification action. Middle position of the solar panel for excitation force on the solar panel in the dust removal concept is the best position.

1. Introduction

Solar panels are the most popular solar system use to convert solar energy directly to electrical energy [1-3]. One of the best-chosen regions for operating of solar panels with high performance was desert areas, due to the availability of solar radiation with high intensity [4] despite the presence of dust accumulation [5], and dust storms which happened frequently in these areas [6], these are the most of critical issues affecting on its operation. Most of the Middle-East countries' areas are deserts, where a high frequent of dust storms and regularly accumulated dust cleaning directly after each one [7] such as in Iraq [8]. Qatar [9], Iran [10], Jordan [11], Saudi Arabia [12]. The weakness of many existing dust removal techniques has been demonstrated by various studies in the last two decades.

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Many of these techniques are designed to consume power from the solar plant with a concept of adding an external force as mention in Kawamoto and Guo [9], without mention to the value of force required to vanquish dust particle adhesive force with solar panel surface [13], whatever this force has a side effect on the solar panel.

The adhesive force depends on the dust particle size and the forces acting on a particle are not identical while the vibrate dust out it would inevitably make damages to solar panels [14]. The particle size, constituents of dust, and their shape vary according to region throughout the world. Furthermore, the deposition characteristics and rates vary dramatically in different localities [15- 16].

Vibration response of the solar panel, which subjected to an external excitation force, figure out the desired position for this force and verified with experimental work of Osam *et al.,* [17] are the main objectives of the current study, where the simulation achieved the solar panel surface not including the supporting structure for it. The maximum force absorbed from Osam *et al.,* [17] is 7.87 N at wind speed 5 m/sec. Therefore ANSYS software was applied to achieve numerical simulation by evaluating solar panel vibration response with excitation force values (2, 4, 6, and 10 Newton) where 15 Newton also applied to be more trusted because wind speed reaching more than 10 m/sec as mention in previous studies [18-19] studies. These excitation force values are tested in harmonic response; the deformation for each tested point was compared with the static structural total deformation at these mode shapes. The frequency of the system must not reach natural frequency [20]. The natural frequency of any structure depends on it is materials and mechanical properties [21]. The material used for manufacturing solar panel is silicon [22]. Transparent plastic Acrylic glass or Poly (methyl methacrylate) called Perspex is widely used in many fields [23] such as solar energy field [24]. Therefore, the current study used Perspex to simulate the panel model BSP32-100 which is a flexible model, the difference in mechanical properties of both materials has been taken into consideration.

2. Methodology

2.1 Solar Panel Numerical Solutions

Finite Element (FE) formulations for the flat plate can be done by; weighted residual approach or direct variational methods [25]**.** Substituted in governing differential equations in weight residuals approach as an approximate solution, obtained the unknown parameters; some weighting function multiplied by residual function then integrating to zero. Supply an external force on the solar panel bottom surface causes a deformation on the upper surface by using ANSYS software. Solar panel considered as a flat plate for analyzing the dynamic behavior

2.1.1 Modeling the solar panel model

SolidWorks software (version 2014) used for solar panel drawing and exported to ANSYS software (Geometry) as shown in Figure 1. Subsequently, chosen Perspex material as a further modification with specifications [26].

2.1.2 Grid independent test (GIT)

Finite Element accuracy depends on the number of elements and nodes [27] which effect the time required for simulation. Meanwhile, a grid size choice is a settlement between the accuracy requirement and computational power [28]. To achieve a converged solution finer grid size with more iteration, while a large grid's size convergence time required is so long. Therefore, lower underrelaxation factors required for the scheme solution to conform solution stability. Determination of appropriate numbers for nodes and elements at high truthful results for solar panel in the current study was done by the grid-independence test (GIT). Solar panel GIT was carried out by the selection of different mesh cases (ten cases) (see Tables 1, 2, and Figure 2). The ten cases were achieved according to the ANSYS guide by natural frequencies comparison for mode shapes as shown in Figure 3. For highly accurate results and simulation time saving, selection of case 5 as a final and best mesh from other cases, hence this case provided low iteration number and acceptable convergence time. Where F1 to F4; are the natural frequencies at first to fourth mode shapes.

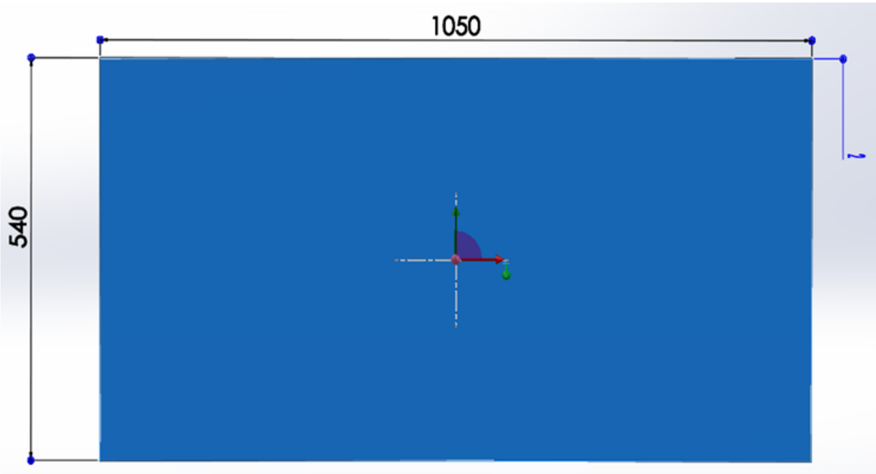


Fig. 1. The solar panel after drawing in solid work software all dimensions in mm

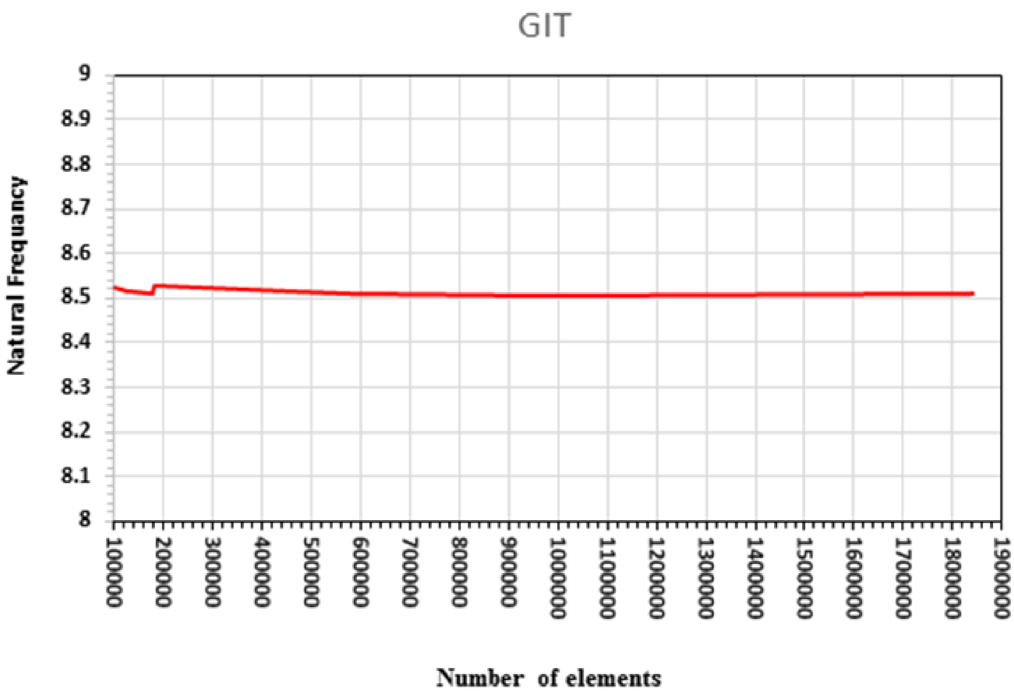


Fig. 2. Grid independent test (GIT) for the first mode shape

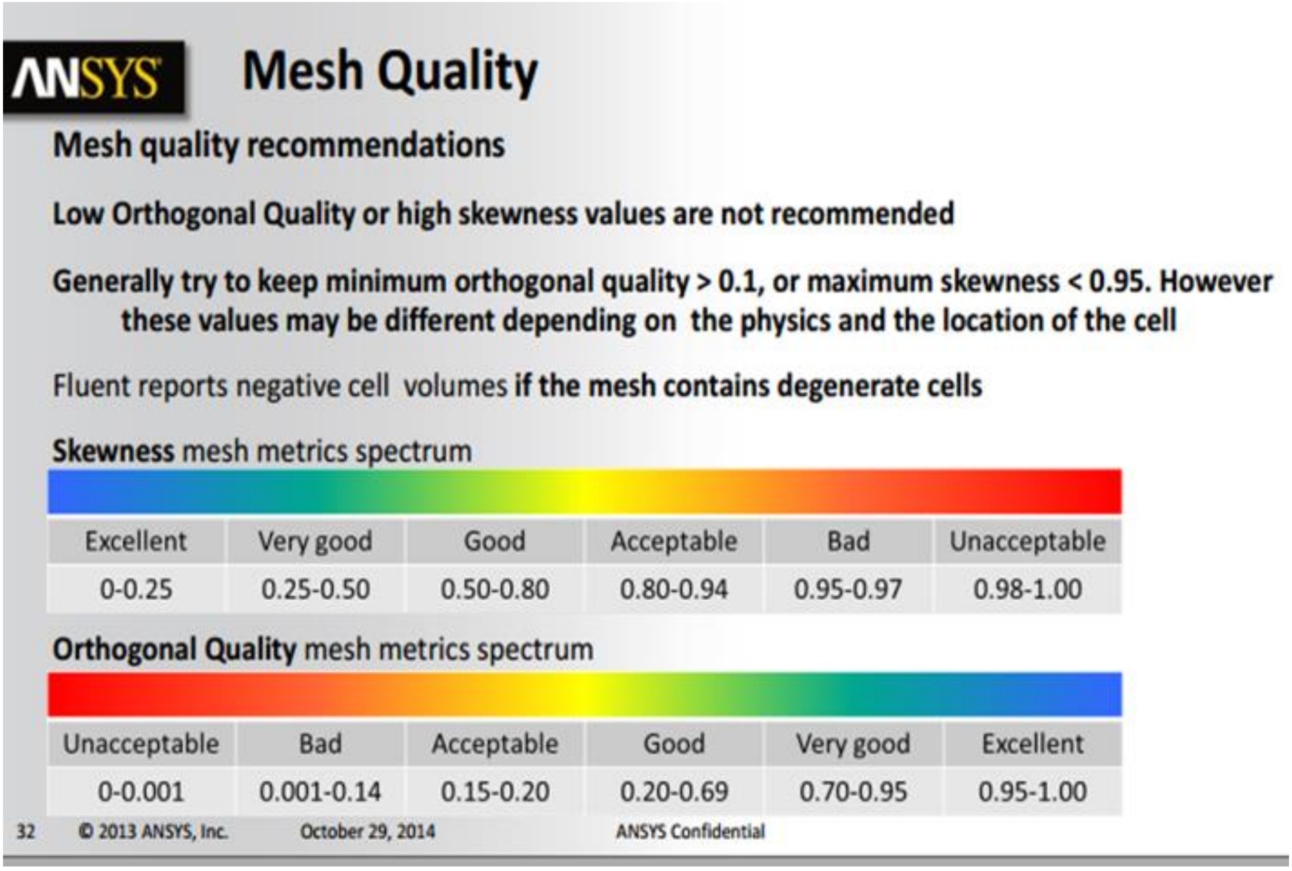


Fig. 3. Mesh quality recommendations [29]

2.1.3 Best location for the excitation force on panel surface

The boundary conditions used in FE analysis were solar panel is fixed from four sides, therefore figure out the best location of the excitation force that provided the major deformation for the panel surface. In the current study, an external force has been added at the bottom of the panel to produce a deformation [30], where dust particles absorbed kinetic energy according to the dust removal concept. Identification of solar panel deformation amount by using ANSYS software 16.1 for numerical process to figure out the impact of force position, according to the mode shape, the highest value of the solar panel deformation was produced, which represents the deformation amount caused by the external force and must be below the deformation of natural frequency [31]. Assuming that; solid object, 0° tilt angle, and four sides fixed support of the solar panel. Testing of five equally distances points along the centerline of the solar panel with the same nodes and elements numbers as in the previous section, as shown in Figure 4. The excitation force values (2, 4, 6, 10, and 15 Newton) are tested in harmonic response; the deformation for each tested point was compared with the static structural total deformation at these mode shapes.

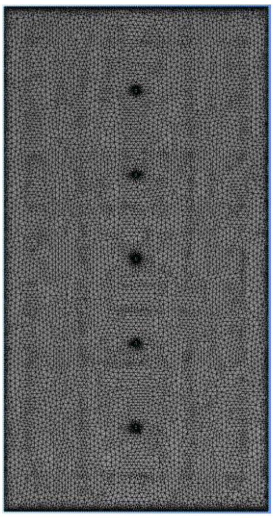
Table 1
Grid independent test (GIT)

No.	Element No.	Nodes No.	Skewness Max.	Skewness Average	Orthogonal Quality Min.	Orthogonal Quality Average	F1	F2	F3	F4
1	101052	194646	0.89320	0.61992	0.12863	0.57410	8.52410	11.2010	15.9610	22.1300
2	129175	246378	0.88288	0.58832	0.15257	0.60250	8.51560	11.1910	15.9490	22.0960
3	137427	2584950	0.87857	0.57607	0.15258	0.61283	8.51570	11.1910	15.9490	22.0970
4	179321	325998	0.85725	0.54979	0.18670	0.63162	8.51140	11.1860	15.9420	22.0770
5	181924	358473	0.71083	0.48134	0.36294	0.69425	8.51280	11.2010	15.9520	22.1110
6	469760	935972	0.60436	0.26007	0.43414	0.83837	8.51660	11.1890	15.9420	22.0780
7	577619	293788	0.64364	0.38058	0.41700	0.76394	8.51160	11.1830	15.9340	22.0650
8	966808	1616667	0.73993	0.48638	0.30363	0.68493	8.50800	11.1800	15.9300	22.0540
9	183724	305216	0.60524	0.36748	0.43126	0.76575	8.51070	11.1820	15.9320	22.0610
10	184052	305713	0.60524	0.36742	0.43126	0.76583	8.51070	11.1820	15.9320	22.0610

2.2 Numerical Simulation Verification

The solar panel with 45 significant nodes number in the experimental part was divided as threshold values to measure the total deformation on the upper surface of solar panel and compared with the numerical simulation with 358,473 numbers of nodes. The deformation experimentally measured by a portable vibration meter (GH:2435488) with a 0° tilt angle and the force has a middle supply point with working range (1.17, 3.25, 4.79, 6.33, 7.87 Newton), as shown in Figure 5.

Table 2
Cases of GIT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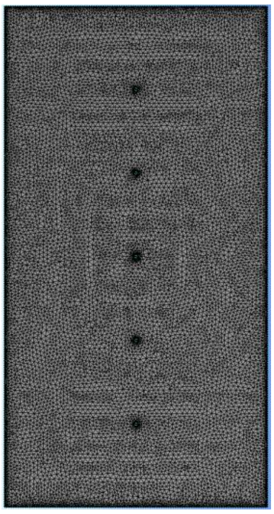
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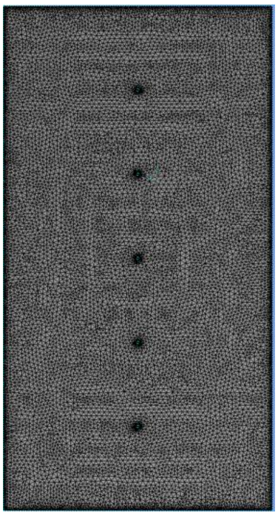
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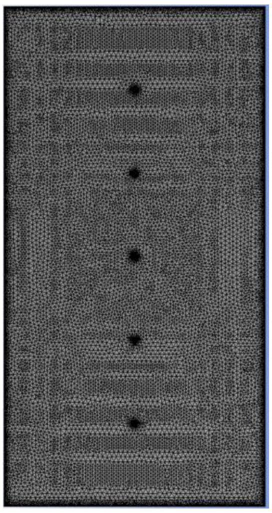
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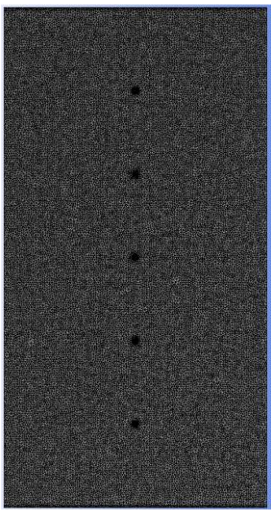
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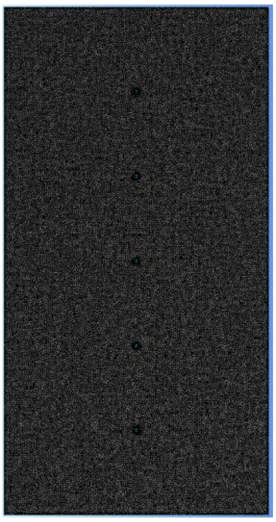
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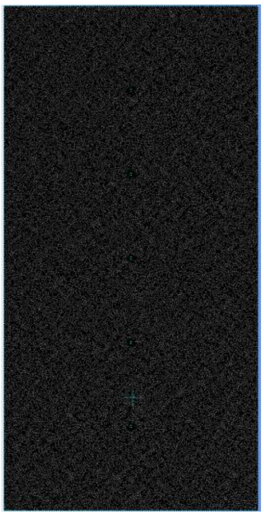
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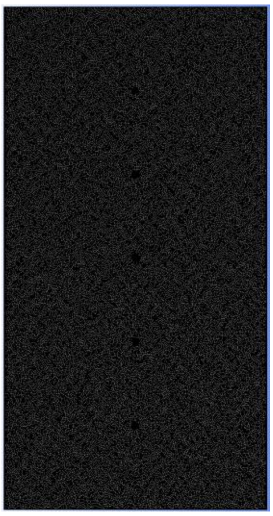
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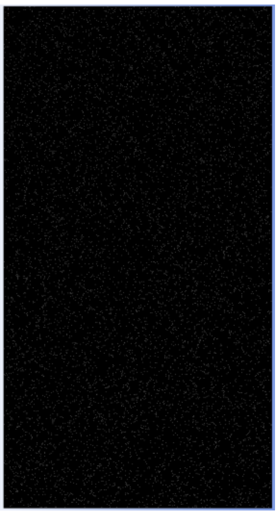
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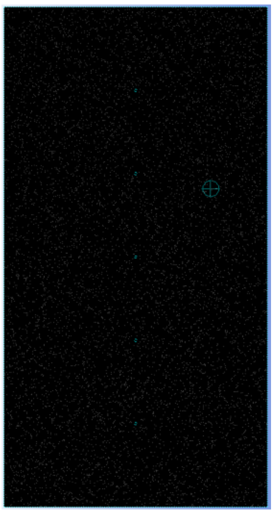

Case 10

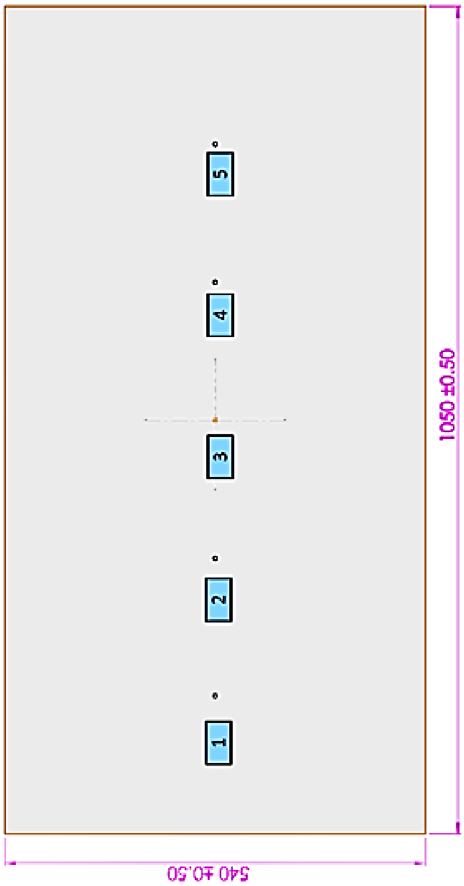


Fig. 4. Five tested points for solar panel

Fig. 5. Photograph of a: PV with 45 points upper surface division, b: Portable vibration meter

3. Results

3.1 Best Location of Excitation Force

The deformation that appeared in the solar panel upper surface due to the harmonic response excitation force which not exceed the natural frequency as mention in the study of Josephs [31]. Therefore, chose the position of high deformation in the upper surface of the solar panel. Six mode shapes (MS) during the numerical process are taking in consideration, where the bending effect mode shape (first one) from the six modes shape have a greater effect than the others and appeared in the calculation as shown in Figure 6, where the mode shape depends on the selected material and the geometric shape, and because of the solar panel is fixed support from the four sides there is no chance to get the other mode shapes. The comparison done according to the deformation of the upper surface for 0° tilt angle must not exceed the value in natural frequency as shown in Figure 7, with frequency over 24 Hz, while Kawamoto and Guo [9] suggested that for PV was inclined at 20°, the frequency of the applied voltage, less than 10 Hz, operation is preferable due to the effect of tilt angle. The middle position (position no. 3) has the highest deformation value from the others which is the same judgment as mention in the study of Yuen *et al.,* [32], according to Figure 1. Table 3 produced the best position of the external force acting on solar panel; while Figures 8 and 9 show that increase in external force causes an increase in deformation value.

Table 3
Maximum total deformation according to natural frequency and force position, at zero tilt angle

Force N	Position 1 (mm)	Position 2 (mm)	Position 3 (mm)	Position 4 (mm)	Position 5 (mm)
2	3.6113	1.3905	3.8591	1.3901	3.6113
4	7.224	2.7809	7.7182	2.7802	7.2227
6	10.836	4.1714	11.577	4.1703	10.834
10	18.06	6.9523	19.296	6.95	18.057
15	27.09	10.428	28.943	10.426	27.085

The maximum deformation caused by an external excitation at the middle point (No. 3) is 28.943 mm at 15 N which is below the deformation at the natural frequency, meanwhile, the total force required to achieve adhesive force is 324nN for dust size 2µm according to study of Said and Walwil [33]. That means subjected of solar panel with external excitation force with the current study rang is safe, while the deformation did not accede the deformation at the natural frequency.

Object Name	Total Deformation	Total Deformation 2	Total Deformation 3	Total Deformation 4	Total Deformation 5	Total Deformation 6
State	Solved					
Scope						
Scoping Method	Geometry Selection					
Geometry	All Bodies					
Definition						
Type	Total Deformation					
Mode	1.	2.	3.	4.	5.	6.
Identifier						
Suppressed	No					
Results						
Minimum	0. mm					
Maximum	2094.1 mm	2021.8 mm	1994.8 mm	1935.6 mm	1979.6 mm	1913.4 mm
Information						
Frequency	8.528 Hz	11.201 Hz	15.952 Hz	22.111 Hz	22.741 Hz	24.712 Hz

Fig. 6. Photograph of six mode shape with maximum deformation

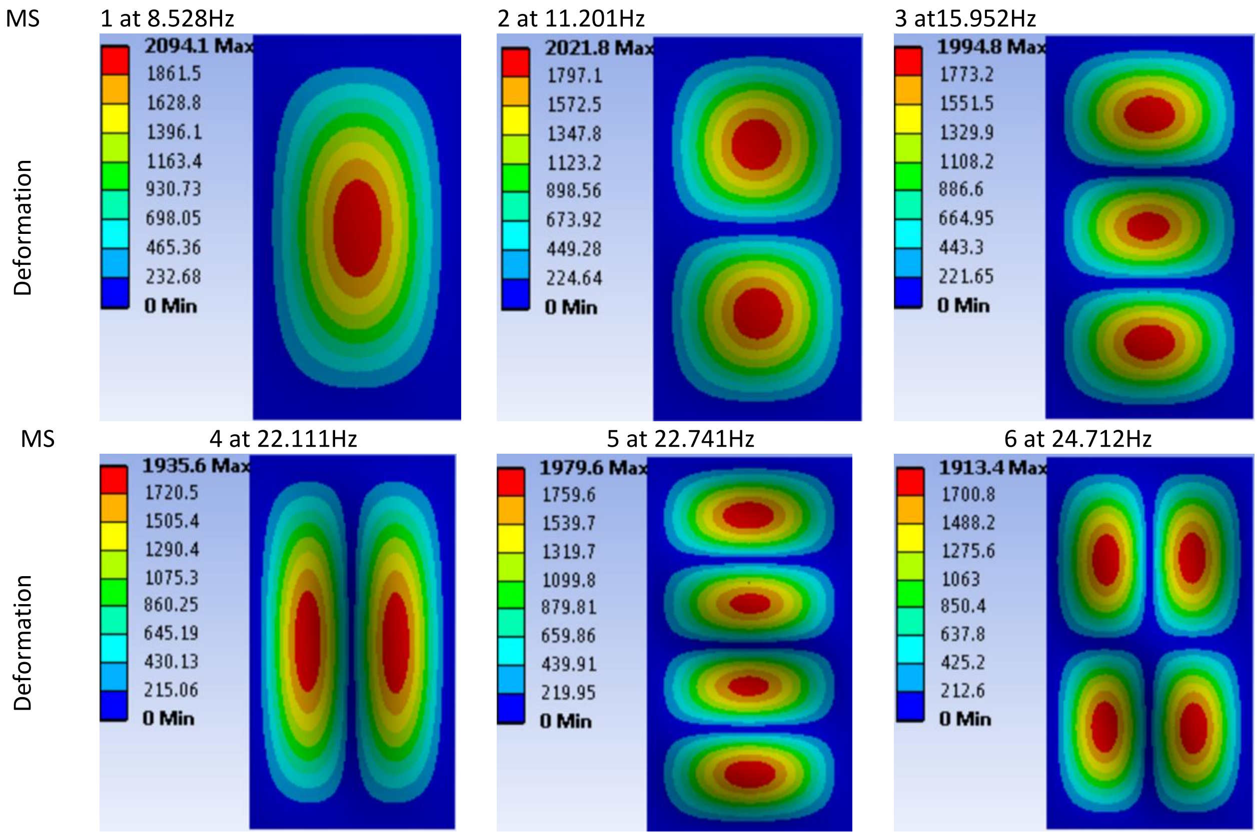
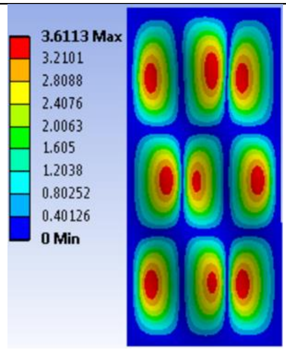
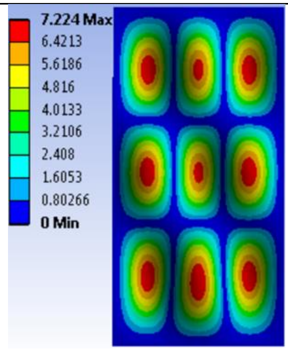
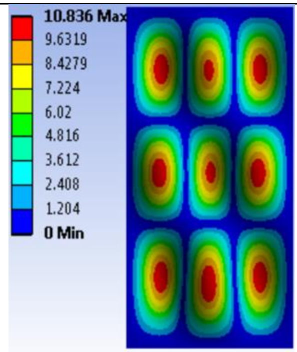
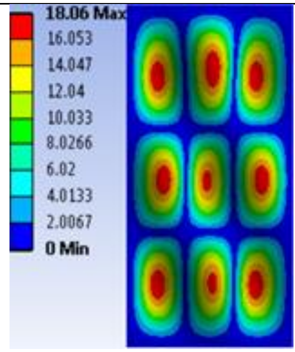
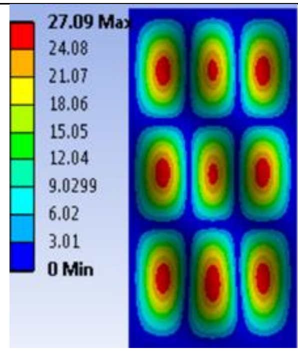
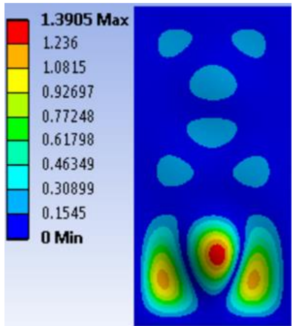
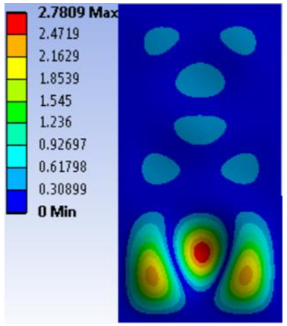
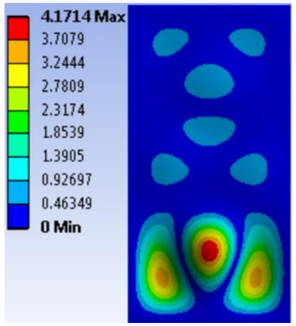
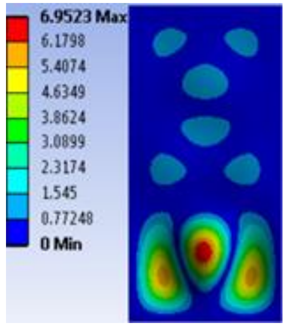
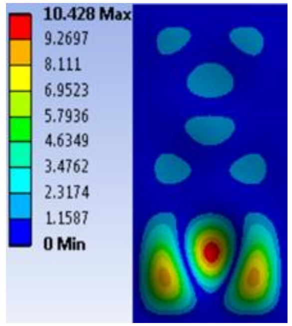
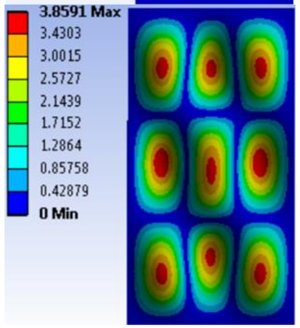
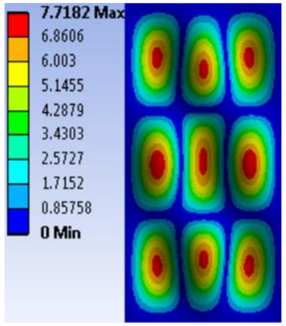
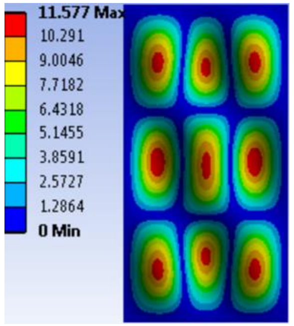
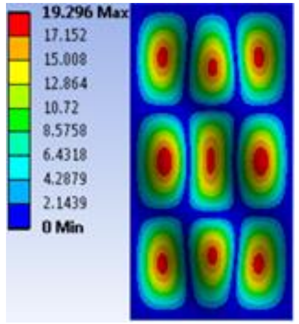
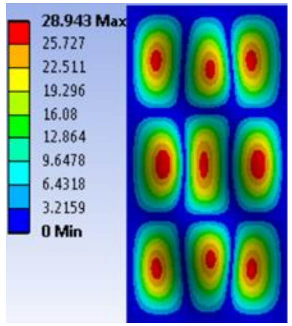


Fig. 7. Total deformation for the six mode shapes at natural frequency

Force N	2N Total Deformation at harmonic force	4N Total Deformation at harmonic force	6N Total Deformation at harmonic force	10N Total Deformation at harmonic force	15N Total Deformation at harmonic force
Force position 1					
Force position 2					
Force position 3					

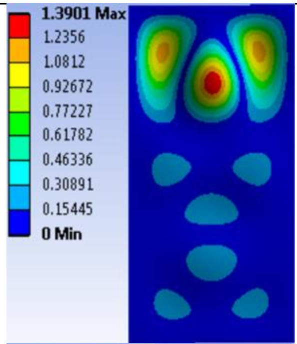
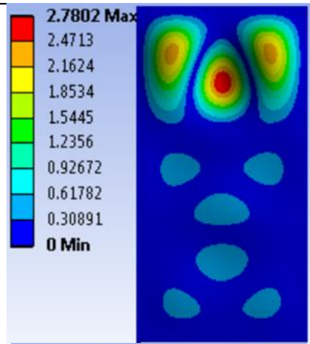
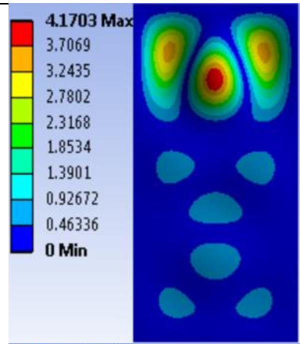
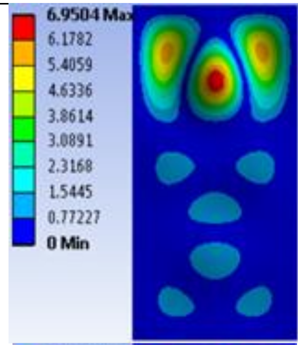
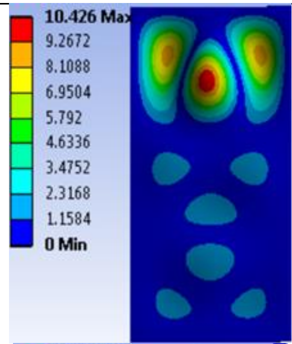
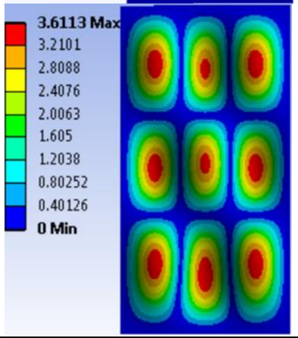
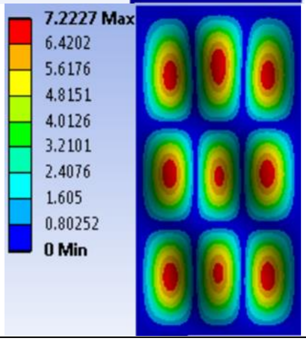
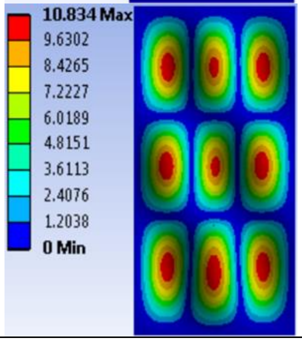
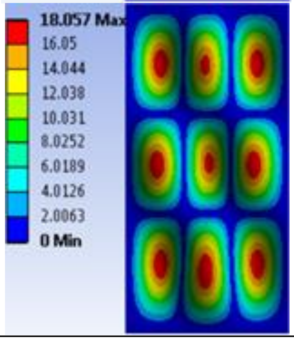
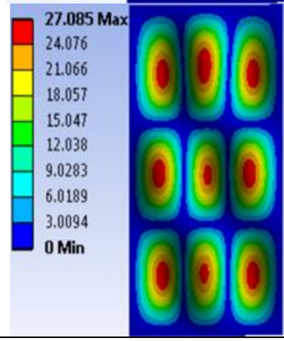
Force N	2N Total Deformation at harmonic force	4N Total Deformation at harmonic force	6N Total Deformation at harmonic force	10N Total Deformation at harmonic force	15N Total Deformation at harmonic force
Force position 4					
Force position 5					

Fig. 8. Maximum deformation for solar panel upper surface according to force magnitude and position

3.2 Verification of Numerical Simulation

External force subjected at solar panel bottom surface causing a deformation on the upper surface or it. Comparison between experiments and numerical was done according to the values of excitation force which absorbed from Attia *et al.,* [17] study, where the force values are 1.71, 3.25, 4.79, 6.33 and 7.87 Newton. Hence, these values applied in numerical analysis and camper the deformation values that appear at the panel surface with experimental values by used manual handling, vibration meter as shown in Figure 10, verification results as shown in Figure 11 are close to 94% and the average deformation values of testing points are 0.07 mm to 1.5 mm.

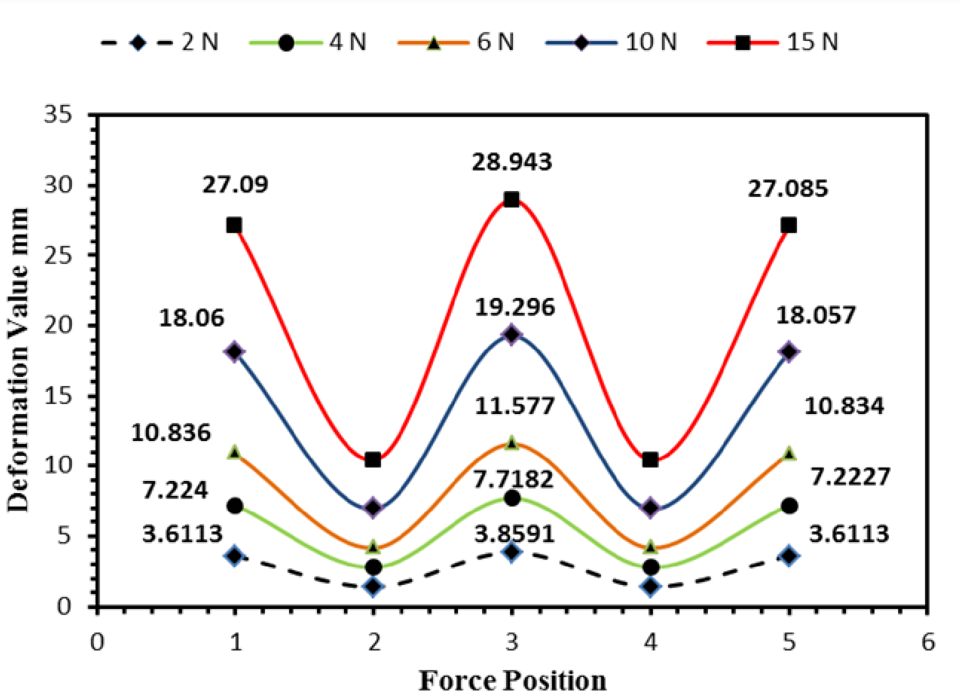


Fig. 9. Effect of force value and its position on solar panel surface deformations

Fig. 10. Experimental average deformation values of testing points

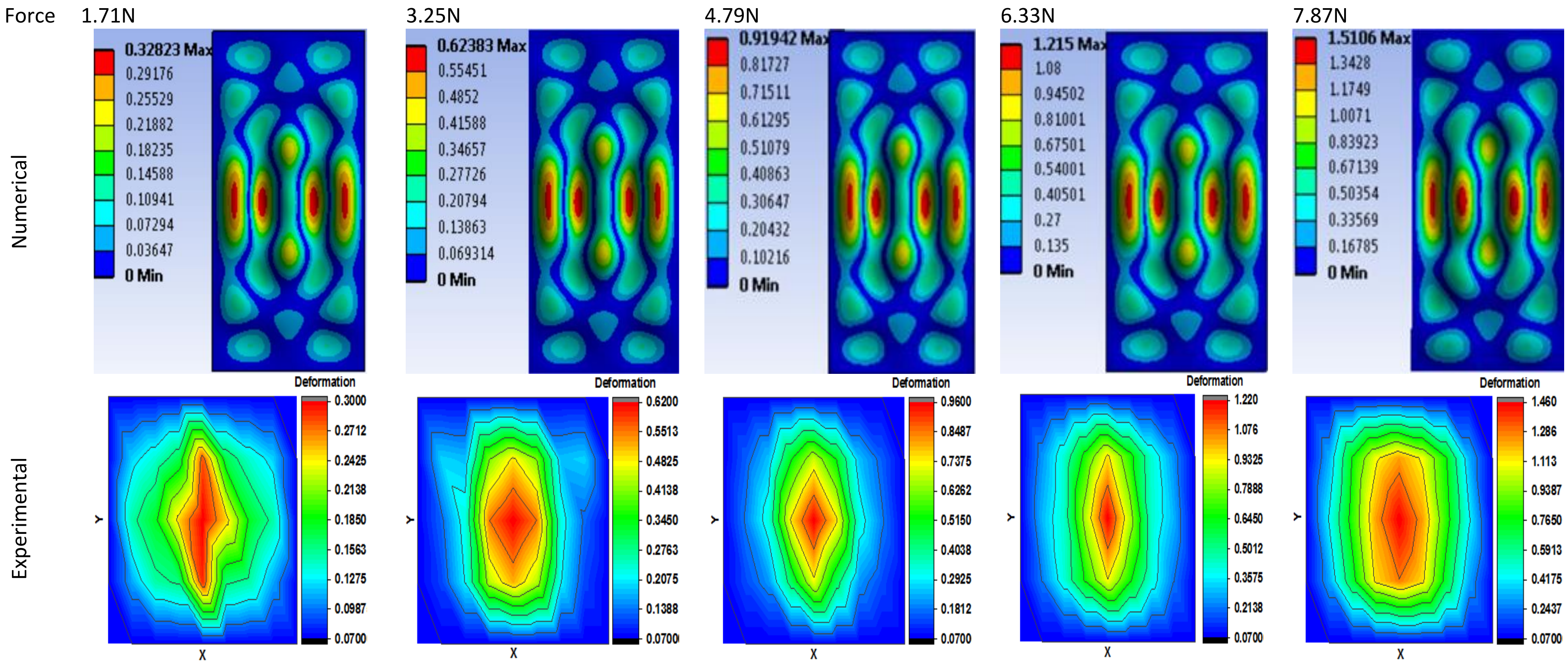


Fig. 11. Solar panel deformation magnitude (mm) subjected to different external excitation forces

4. Conclusions

Renewable energies have many types utilized in many fields to produce electrical power instead of fossil fuels, especially solar energy. Sited of the solar system in open, dry, and semi-arid areas where facing a considerable challenge of dust accumulation. Therefore, dust removal from the solar panel using a suitable technique will improve its efficiency. Most of these techniques adopted the concept of dust removal by adding an external excitation force to overcome the adhesive force between dust particles and panel surface. Based on the numerical program and verification processes, the response of the solar panel from adding an external excitation force, conclusions are summarized as follows: Deformation value increases in solar panel surface with the increase in external excitation force.

I. Solar panel surface deformations must not exceed the value in natural frequency.
II. The middle position of the solar panel is the best position of excitation force acting on a solar panel on the concept of dust removal with four sides fixed supports.
III. Comparison between experiment and numerical showed a good agreement was close to 94% and the average deformation values of testing points are 0.07 mm to 1.5 mm and not exceed the deformation of the first mode shape.
IV. The reduction value of external excitation force due to the tilt angle is an insignificant and can be neglected in this study.
V. Solar panel model BSP32-100 subjected to an external excitation force in the terms of dust removal close to 15 N and should not exceed the natural frequency.

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