# Tilt Angle Optimization and Formulation of Annual Adjustment Models for a Solar Power Plant Setup-able Site at Himachal Pradesh, India

**Anchal Awasthi, Anand Mohan, Ashutosh Sharma**

***Abstract:*** ***Solar tracking devices are quite effective for collecting maximum solar radiations but for vastly spread solar energy collection plant, their usage is suppressed due to large cost involvement. The best alternative to this problem is adjustment of tilt angle at most appropriate position. In this study monthly optimum tilt angle have been identified for a solar power plant setup-able site Kalth (φ 30.85046˚, L 77.06153˚), situated at Himachal Pradesh, India. For diffuse radiation estimation, an isotropic model has been used. By considering the impracticality involved in monthly tilt angle adjustment, various annual adjustment models have been formulated for two, three and four annual adjustments. In order to estimate the increment in solar insolation by adopting these models, Performance Enhancement (PE) have been computed from the conventional method of setting the solar collector tilt equal to latitude angle. The results show that PE is maximum for monthly optimum tilt angles followed by M-4 which is a three annual adjustment model. Based on PE requirement, any of the proposed models can be selected for setting up solar energy collection plant at suggested site.***

***Keywords : Annual adjustment model, solar collector, solar power plant setup-able site, tilt angle optimization***

## I. INTRODUCTION

Solar energy is amongst clean energy resources and available in abundance. It can be utilized both in thermal and electricity form. The solar collectors either thermal or PV panels can collect maximum solar energy by appropriate orientation towards sun. Application of solar tracking devices for vastly spread solar power plants is not economically beneficial [1]. Adjustment of tilt angle of solar collector at optimum position can resolve this problem at large extent [2]. Various studies have been carried out in literature for optimizing the tilt angle for solar collectors. Wessley et al. [3] determined optimum tilt angle for eight Indian cities and also developed a correlation for yearly optimum tilt angle for these sites.

**Revised Manuscript Received on May 30, 2020.**
***** Correspondence Author

**Anchal Awasthi**, Electrical Engineering Department, AP Goyal Shimla University, Shimla, India. Email: anchalawasthi23@gmail.com

**Anand Mohan**, Electrical Engineering Department, AP Goyal Shimla University, Shimla, India. Email: anand1mohan@gmail.com

**Ashutosh Sharma***, Mechanical Engineering Department, Dr B R Ambedkar National Institute of Technology, Jalandhar, India. Email: ashutoshs.me.19@nitj.ac.in



In another study, Benghanem [4] computed monthly optimum tilt angles for Madinah, Saudi Arabia. The author observed a loss of 8% for conventional method of tilting the solar collector at latitude from the monthly optimum tilt angles. Soulaymana and Sabbagh [5] determined the optimum tilt angle for tropical regions and found that the system oriented at optimum tilt angle yields 11 to 18 percent more than conventionally oriented system. Ghosh et al. [6] considered three models viz. isotropic, Klucher and Perez for estimating solar insolation and optimum tilt angle determination at Dhaka, Bangladesh. Authors reported percentage increment upto 55 and 15 percent at monthly and yearly optimum tilted collectors from collector tilted at local latitude. Implementation of monthly optimum tilt angle is not feasible practically due to much tediousness involvement and cost association. To overcome this problem different seasons have been considered in literature. Various studies [7-10] considered four seasons: Autumn (September-November, Winter (December-February), Spring (March-May) and Summer (June-August). Skeiker [7] and Ismail et al. [8] reported that the net decrease in solar insolation by considering seasons was 2% and 0.8% in reference to monthly optimum tilt angle respectively. Despotovic and Nedic [1] considered different scenarios of seasons and found that the solar insolation collected by biannual tilt angle adjustment is minutely less than four adjustment seasons. The literature indicates the significance of optimum tilt angle determination and annual adjustment models for a solar power plant. In the current study monthly optimum tilt angle has been identified for a location Kalth, situated in Himachal Pradesh, India (φ 30.85046˚, L 77.06153˚). The location selection has been done by considering the suitability for solar power plant setup. By taking in account the cost association with monthly optimum tilt angle adjustment, different adjustment models has been considered for four, three and two adjustments per year. Comparison of these models has been carried out to find most appropriate one. The next section discusses the methodology adopted for attainment of desired objectives.

## II. METHODOLOGY

### A. Optimum Tilt Angle Determination

This section discusses the important relations and methodology adopted for modeling of optimum tilt angles. The optimum tilt angles have been determined by maximizing the global insolation for selected site. The global insolation at any surface is function of direct, diffuse and reflected radiations.

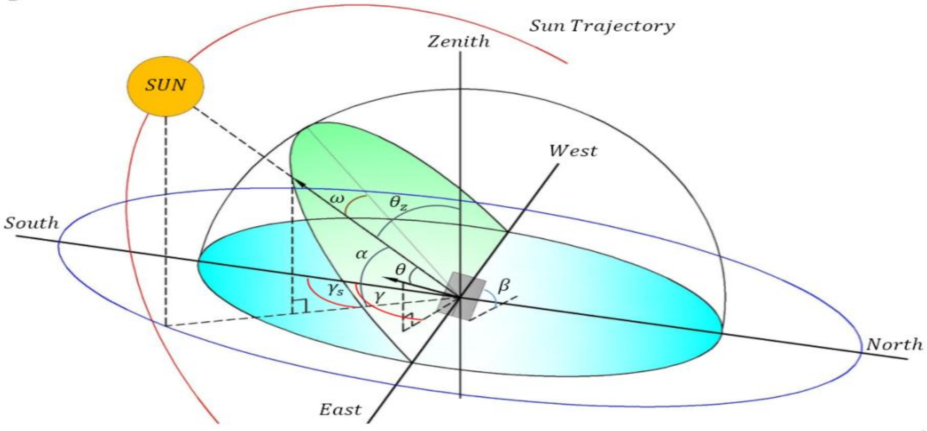


**Fig. 1.Schematic of solar angles for flat plate collector**

In order to estimate diffuse radiations, various models have been suggested in literature. Yadav and Chandel [11] carried out a comparative study of these models for Himachal Pradesh, India and found Liu and Jordan model [12] most accurate. This model has been used in this study for estimating the diffuse radiations. Global insolation on a tilted surface ($H_{g,t}$) be calculated by

$$H_{g,t}\ (KWh/m^2/day) = (H - H_d)R_B + H_d\left(\frac{1+\cos\beta}{2}\right) + H.\rho_g.\left(\frac{1-\cos\beta}{2}\right) \quad (1)$$

Where, $H$ is global insolation on horizontal surface, $R_B$ is ratio of the beam radiation on tilted and horizontal surface, $H_d$ is diffuse radiation on horizontal surface, $\rho_g$ is reflection factor and $\beta$ is tilt angle.

Data for global insolation on horizontal surface ($H$) have been taken from Surface Meteorology and Solar Energy (*SSE*) datasheets provided by NASA, USA. This data for Kalth ($\varphi$ 30.85046˚, $L$ 77.06153˚) from 2014 to 2017 have been presented in Table-I.

**Table- I: Data for global insolation on horizontal surface**

| Mont h | Monthly Average global insolation on horizontal surface (H) (kW-hr/m$^2$/day) | | | | |
|---|---|---|---|---|---|
| | *2014* | *2015* | *2016* | *2017* | *Average* |
| Jan | 3.12 | 2.94 | 3.38 | 3.03 | 3.1175 |
| Feb | 3.84 | 4.08 | 4.43 | 4.47 | 4.205 |
| Mar | 4.89 | 4.92 | 5.06 | 5.48 | 5.0875 |
| Apr | 6.31 | 6.03 | 6.41 | 6.62 | 6.3425 |
| May | 6.66 | 6.83 | 6.82 | 6.39 | 6.675 |
| Jun | 6.56 | 5.91 | 5.96 | 5.44 | 5.9675 |
| Jul | 4.66 | 4.5 | 4.23 | 4.53 | 4.48 |
| Aug | 5.4 | 4.63 | 4.26 | 4.54 | 4.7075 |
| Sep | 4.98 | 5.43 | 5.19 | 4.87 | 5.1175 |
| Oct | 4.74 | 4.98 | 4.94 | 5.18 | 4.96 |
| Nov | 4.1 | 3.8 | 4.08 | 3.87 | 3.9625 |
| Dec | 3.17 | 3.25 | 3.47 | 3.11 | 3.25 |

$R_B$ can be stated as,

$$R_B = \frac{\cos\theta}{\cos\theta_Z} = \frac{\cos(\varphi-\beta)\cos\delta\ \sin\omega_S + \omega_S\sin(\varphi-\beta)\sin\delta}{\cos\delta\ \sin\omega\cos\varphi + \omega_S\sin\varphi\sin\delta} \quad (2)$$

Where $\theta$, $\theta_Z$, $\delta$ and $\omega_s$ are incidence angle, zenith angle, declination angle and sunset angle respectively. These angles can be visualized from Figure 1. Expression for computing $\delta$ and $\omega_s$ are as follow,

$$\delta = 23.45\sin\left(360\frac{284+n}{365}\right) \quad (3)$$

$$\cos\omega_s = -\frac{\sin\varphi\sin\delta}{\cos\varphi\cos\delta} = -\tan\varphi\tan\delta \quad (4)$$

$H_d$ depends on clearness ratio ($k_T$) and $H$, and is given by equation

For $\omega_s \leq 81.4^{\circ}$

$$\frac{H_d}{H} = 1.391 - 3.56k_T + 4.189{k_T}^2 - 2.137{k_T}^3 \quad (5)$$

And for $\omega_s \geq 81.4^{\circ}$

$$\frac{H_d}{H} = 1.311 - 3.022k_T + 3.427{k_T}^2 + 1.821{k_T}^3 \quad (6)$$

Where $k_t$=$H/H_0$, in this equation, $H_0$ are extraterrestrial radiations on horizontal surface and for any Julian day ($n$) of year its value can be evaluated as,

$$H_o\ (KWh/m^2/day) = \frac{24\times G_{SC}}{\pi}\left(1+\left(0.033\cos\left(\frac{360n}{365}\right)\right)\right) \quad (7)$$

Where $G_{SC}$ is global solar constant ($G_{SC}$=$1367\ W/m^2$). Yearly optimum tilt angle has been estimated as average of optimum tilt angles for all the months. The flow chart of the computational model has been presented in Fig. 2.

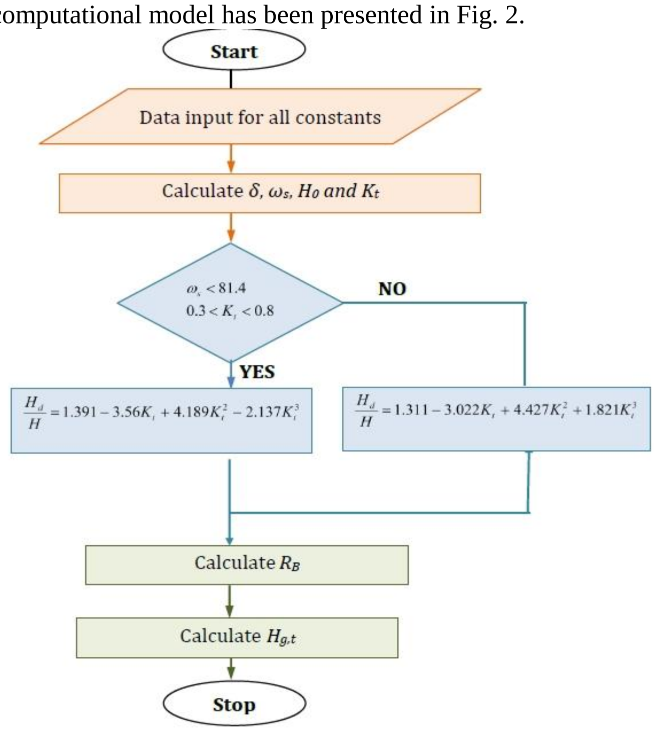


**Fig. 2. Flow chart of the computational model**

### B. Adjustment Models

Monthly adjustment of tilt angle for large solar energy collection plant is not possible practically. So, different adjustment models have been formulated based on number of annual adjustments of four, three and two. These models have been presented in Table-II.

**Table- II: Different annual adjustment models**

| Sr. No | Two Annual adjustments | | Three Annual Adjustments | | Four Annual Adjustment | |
|---|---|---|---|---|---|---|
| | *M-1* | *M-2* | *M-3* | *M-4* | *M-5* | *M-6* |
| 1 | Jan-Jun | Oct-Mar | Jan-Apr | Oct-Feb | Jan-Mar | Nov-Jan |
| 2 | Jul-Dec | Apr-Sep | May-Aug | Mar-Apr | Apr-Jun | Feb-Apr |
| 3 | | | Sep-Dec | May-Sep | Jul-Sep | May-Jul |
| 4 | | | | | Oct-Dec | Aug-Oct |

Performance enhancement (PE) of the different models from the conventional method of setting up solar collector tilt equal to latitude angle have been computed by following relation

$$PE\ (\%age) = \left(\frac{(H_{g,t})_{\beta} - (H_{g,t})_{\beta=\varphi}}{(H_{g,t})_{\beta=\varphi}}\right) \times 100 \qquad (8)$$

## III. RESULTS AND DISCUSSION

The optimum tilt angles for selected site ($\varphi$ 30.85046˚, $L$ 77.06153˚) have been computed by adopting the suggested methodology. These angles are presented in Fig. 3. The optimum tilt angle varies between 0º and 54º. The maximum tilt angles are observed for November to January (53º-54º-52º) and minimum for May to July (0º-0º-0º).
Various seasonal adjustment models have been designed and values of tilt angles for these models are presented in Fig. 4. These values have been found by averaging the optimum tilt angles of corresponding months. The monthly average insolation computed by considering different models has been presented in Table 3. In order to compare these models, annual average insolation over tilted surface from different models has been presented in Fig. 5. It can be clearly seen that the monthly optimum tilt angle collects maximum insolation. Amongst the suggested models, model-2, Model-4 and Model 5 gives maximum value of average annual insolation among two, three and four seasonal adjustment models respectively.

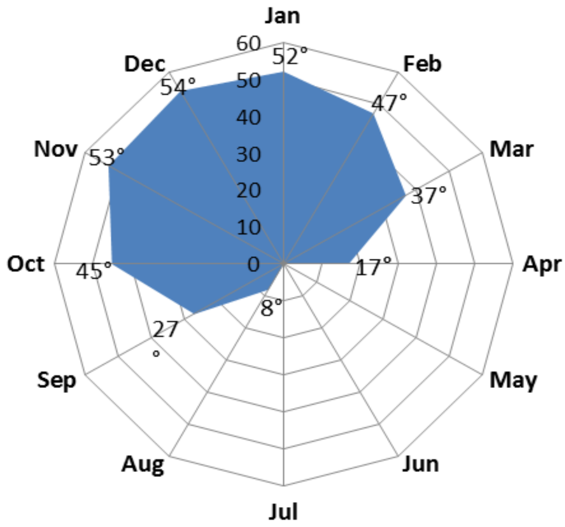


**Fig. 3. Optimum tilt angles (Degrees) for different months**

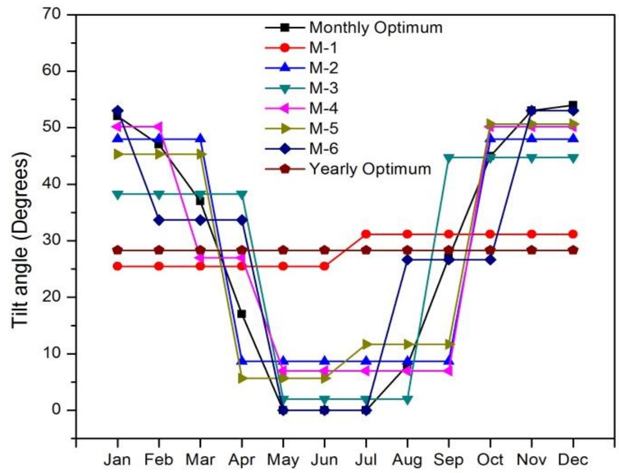


**Fig. 4. Tilt angle for different annual adjustment models**

**Table-II: Global insolation over tilted surface (kW-hr/m²/day) corresponding to different models**

| Month | Monthly Optimum | M-1 | M-2 | M-3 | M-4 | M-5 | M-6 | β=φ | Yearly Optimum |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 4.04 | 3.69 | 4.04 | 3.98 | 4.04 | 4.03 | 4.04 | 3.72 | 4.04 |
| Feb | 5.28 | 4.97 | 5.28 | 5.24 | 5.27 | 5.27 | 5.18 | 5.14 | 5.18 |
| Mar | 5.73 | 5.69 | 5.61 | 5.72 | 5.70 | 5.65 | 5.73 | 5.73 | 5.73 |
| Apr | 6.53 | 6.48 | 6.48 | 6.22 | 6.46 | 6.45 | 6.34 | 6.40 | 6.34 |
| May | 6.68 | 6.20 | 6.61 | 6.67 | 6.63 | 6.64 | 6.68 | 5.99 | 6.68 |
| Jun | 5.97 | 5.35 | 5.84 | 5.95 | 5.87 | 5.89 | 5.97 | 5.14 | 5.97 |
| Jul | 4.48 | 4.01 | 4.42 | 4.47 | 4.44 | 4.39 | 4.48 | 4.02 | 4.48 |
| Aug | 4.73 | 4.51 | 4.73 | 4.72 | 4.73 | 4.73 | 4.59 | 4.52 | 4.59 |
| Sep | 5.51 | 5.50 | 5.33 | 5.35 | 5.29 | 5.38 | 5.51 | 5.51 | 5.51 |
| Oct | 6.19 | 5.99 | 5.89 | 5.96 | 6.18 | 6.17 | 5.98 | 6.06 | 5.98 |
| Nov | 5.33 | 4.88 | 5.32 | 5.29 | 5.32 | 5.32 | 5.33 | 5.08 | 5.33 |
| Dec | 4.33 | 3.91 | 4.32 | 4.30 | 4.33 | 4.33 | 4.33 | 4.12 | 4.33 |

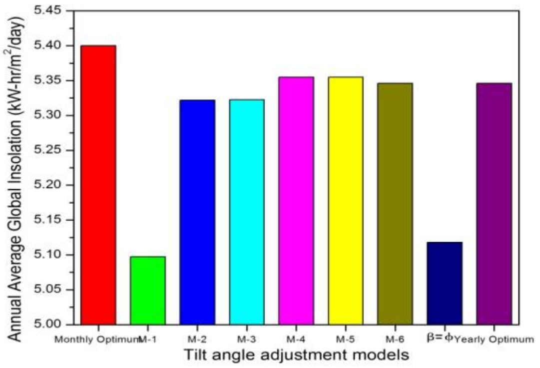


**Fig. 5. Annual average global insolation from different tilt angle models**

At the selected site for tilt angle optimization, most of the rooftop solar energy collection systems have been setup at tilt equal to latitude. In order to estimate the effectiveness of study, a performance enhancement (*PE*) analysis of the most effective models, yearly and monthly optimum angle models have been done from solar collector tilted at latitude(i.e. $\beta=\varphi$) and results are presented in table 3. The descending order of maximum PE from different models is Monthly optimum>M-4>M-5>Yearly optimum>M-2. Monthly optimum tilt angles give maximum PE followed by M-4 which is three seasonal adjustment models.

**Table-III: PE for different models from $\beta=\varphi$.**

| Sr. No. | Adjustment Model | Performance Enhancement (PE) (%age) |
|---|---|---|
| 1 | Monthly Optimum | 5.51 |
| 2 | M-2 | 3.98 |
| 3 | M-4 | 4.63 |
| 4 | M-5 | 4.63 |
| 5 | Yearly Optimum | 4.45 |

## IV. CONCLUSION

The literature signifies that the optimum tilt angle determination is must for collecting maximum solar radiations. The present study discusses the optimum tilt angle determined at different levels for Kalth ($\varphi$ 30.85046˚, *L* 77.06153˚), Himachal Pradesh, India. The following broad conclusion can be drawn from the study:

- The monthly optimum tilt angle varies from 0° to 54° for which the maximum values are observed in November to January and minimum for May to July.
- By considering the impracticality of monthly optimum tilt angle different models have been formulated for two, three and four annual adjustments. The order of insolation over this surfaces is M-4>M-5>M-2.
- In order to calculate the enhancement in performance from conventionally tilted solar collectors at latitude angle, PE have been computed for most effective models and the order found to be, Monthly optimum>M-4>M-5>Yearly Optimum>M-2.

The current study suggests the monthly, yearly and different effective models for tilt angle adjustment. Based on requirement of PE, any of these models can be chosen for executing the solar energy collection plant at the suggested site.

## ACKNOWLEDGMENT

The authors thankful to Surface Meterological and Solar energy (SSE) web portal which is being supported by NASA LaRC Power project, for providing the essential data required in this study. Authors would also like to acknowledge Green Hills Engineering College, Solan, HP for providing experimentation facilities.

## REFERENCES

1. M. Despotovic and V. Nedic, "Comparison of optimum tilt angles of solar collectors determined at yearly, seasonal and monthly levels," *Energy Conversion and Management*, vol. 97, 2015, pp. 121-131.
2. R. Myhan, J. Bieranowski, Z. Szwejkowski and E. Sitnik, "The effect of local meteorological conditions on the optimal tilt angle of a solar energy collector – a case study in Poland," *Journal of Solar Energy Engineering*, vol. 139(4), 2017, 044501.
3. G. Wessley, R. Starbell and S. Sandhya, "Modeling of optimal tilt angle for solar collectors across eight Indian cities," *International Journal of Renewable Energy Research*, vol. 7(1), 2017, pp. 353-358.
4. M. Benghanem, "Optimization of tilt angle for solar panel: Case study for Madinah, Saudi Arabia," *Applied Energy*, vol. 88(4), 2011, pp. 1427-1433.
5. S. Soulaymana and W. Sabbagh, "Optimum tilt angle at tropical region," *International Journal of Renewable Energy Development*, vol. 4(1), 2015, pp. 48-54.
6. H. Ghosh, N. Bhowmik and M. Hussain, "Determining seasonal optimum tilt angles, solar radiations on variously oriented, single and double axis tracking surfaces at Dhaka," *Renewable Energy*, vol. 35(6), 2010, pp. 1292-1297.
7. K. Skeiker, "Optimum tilt angle and orientation for solar collectors in Syria," *Energy Conversion and Management*, vol. 50(9), 2009, pp. 2439-2448.
8. F. Sultan, F. Ali and T. Razaq, "Tilt angle optimization of solar collectors for maximum radiation in three Iraqi cities," *International Journal of Engineering and Industries*, vol. 3, 2012, pp. 99-107.
9. M. Ismail, M. Moghavvemi and T. Mahlia, "Analysis and evaluation of various aspects of solar radiation in the Palestinian territories," *Energy Conversion and Management*, vol. 73, 2013, pp. 57-68.
10. H. Khorasanizadeh, K. Mohammadi and A. Mostafaeipour, "Establishing a diffuse solar radiation model for determining the optimum tilt angle of solar surfaces in Tabass, Iran," *Energy Conversion and Management*, vol. 78, 2014, pp. 805-14.
11. P. Yadav and S.S. Chandel, "Comparative Analysis of Diffused Solar Radiation Models for Optimum Tilt Angle Determination for Indian Locations," *Applied Solar Energy*, vol. 50(1), 2014, pp. 53-59.
12. B. Y. H. Liu and R.C. Jordan, "Daily insolation on surfaces tilted towards the equator," ASHRAE Transactions, 1962, pp. 526-541.

## AUTHORS PROFILE

**Anchal Awasthi** pursuing Master of Technology (M. Tech) at department of Electrical engineering from AP Goyal Shimla University, HP, India. She has received her bachelors of technology (B.Tech) in Electrical Engineering with honors from Himachal Pradesh Technical University, HP, India. She had worked as Lecturer in Electrical Engineering Department at L.R. Polytechnic College, Solan, HP, India affiliated to Himachal Pradesh Takniki Shiksha Board (HPTSB), Dharmashala, HP, India. She has attended numerous conferences, courses and has communicated other relevant work for publication to peer-reviewed journals. The major research areas in which she is keenly interested includes renewable energy, solar PV cells and power systems.

**Dr.Anand Mohan** is currently working as Professor in the Department of Electrical Engineering, underneath the School of Technology and Sciences at AP Goyal Shimla University, Shimla, India. He is also looking after for School of Technology and Sciences as Dean. He has more than 15 Years for academic, administrative and industrial experience in various renowned organizations of India.

He has written more than 15 research manuscripts in International and National Journals and conferences. He has been the reviewer of many journals of repute in India as well as abroad. He has got his Ph. D in the field of Power System Engineering from University of Petroleum and Energy Studies, Dehradun, India. He is the member of many Technical Societies like The Institution of Engineers and IAENG etc. Recently has been invited as Speaker in the International Conference on Machine Learning and Intelligent Systems (MLIS 2019) at National Dong Hwa University, Taiwan. He also expressed in the 6th Annual World Congress of InfoTech-2019, with the theme of “Launch a New Era of 5G and Global Future Network”, held on May 10-12, 2019 at Nanjing, China. He was the Special invited member of Board of Studies of Electrical Engineering for HPTU, Hamirpur. He is the regular speaker in the Short Term Courses organized by of National Institute of Technical Teacher Training and Research (NITTTR), Chandigarh.

**Ashutosh Sharma** is a research scholar (pursuing Ph.D) at Department of Mechanical Engineering at Dr B R Ambekdar National Institute of Technology, Jalandhar. He has completed his Master of technology (M.Tech) in Mechanical Engineering with gold medal (certificate of merit) from Shoolini university, HP, India. He has completed his Bachelors of Technology (B.Tech) in Mechanical Engineering with college level merit certificate from Himachal Pradesh University, Shimla, HP, India. He has worked as Lecturer in Mechanical Engineering department at Green Hills Polytechnic, Solan, HP, India affiliated to HPTSB, Dharamshala, HP, India. He has attended many national/international conferences and have published his work in many reputed journals. He is enthusiastic for research in renewable energy, solar energy and thermal engineering.