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QUANTIFY IMPACT OF GREEN AND SUSTAINABLE TECHNOLOGIES ON AGED DISTRIBUTION SYSTEM

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ABSTRACT

Life of transformer depends on its insulation, which varies due to winding hot spot temperature (HST). Temperature is one of the important factor which affects transformer aging according to IEEE Std C57.91. The HST basically depends upon ambient temperature, top oil temperature (TOT) rise over ambient temperature and HST rise over TOT rise. This paper performs an existing 200kVA oil-type residential distribution transformer (DT) life expectancy analysis to evaluate the impact of solar radiation, wind velocity, electric vehicle (EV) and photo voltaic (PV) penetration for one day. This study presents a probabilistic approach using monte carlo to quantify the impact of weather, green technology as PV and EV to estimate DTs loss of life. Monte carlo method is used for analyzing uncertainty propagation, in this study the unpredicted parameters are solar generation and EV charging pattern. Monte carlo is best suited for random data handling applications. The results presented in this paper are cross-verified as, analytical HST results are compared with matlab/simulink model, analytical loss of life results are compared with monte carlo method and optimum sizing of battery solution is provided by particle swarm optimization method (PSO).

Key words: Loss of Life, Electric Vehicle, Rooftop PV, Monte Carlo, Particle Swarm Optimization.

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1. INTRODUCTION

The Load losses generate the heat which increases the insulation temperature and the aging of DT accelerates with rise in TOT and HST. The objective of this proposed work is to study individual and collective impact of temperature, PV and EV on DT to estimate its loss of life. This study investigates considering only one DT and its associated loads. Moreover PV and storage was also integrated with load therefore the impacts shown from this investigation can be a major concern for the future in large scale such integration into the grid.

The impact of increasing ambient temperature on distribution transformer loss of life is assessed. The rise in ambient temperature may be due to any reason will obviously result in loss of life of transformer and urbanization is also one of them. The impact of ambient temperature change on distribution transformer life is assessed by author [1-3], considering top oil temperature rise for calculating loss of life with the outcome of reduction of life by 3-6 years. The PVsyst predicts the system behavior along with hourly operational disturbances [4]. The study revealed in [5], about the fact that tilt angle and orientation of rooftop SPV installation varies its generation. The case study explained in [6], is carried out in Indian city of Mumbai reveals that rooftop solar photovoltaic generation contributes distribution system mainly during morning partial peak, morning peak and afternoon partial peak. The mineral oil-immersed transformers thermal aging and thermal ratings are studied well in [7-10] in IEEE–C57.91 and IEC-354. The Author has focused on, impact of PV penetration on the life of DT in [11], with outcome of PV penetration increases life until power flow reversals occur. Increase in winding hot-spot temperature by 1.2°C higher than normal conditions in worst case loading scenario can reduce life of distribution transformers (DT) by 8.3% [12]. With 100% rooftop solar PV penetration the loss-of-life (LOL) was reduced by 75% considering 3.3 kW plug-in electric vehicles charging, explained in [13]. The low-voltage (LV) transformer aging rate is quadratic stated in [14-16], when plug-in hybrid electric vehicles (PHEV) are present in system. In the distribution system with low PV and high EV penetration the electrical energy storage system (EESS) capacity required is less as stated in [17]. Deploying EESS can control the serious voltage quality issues persist with high PV and EV penetration network.

2. LOCATION AND DATA COLLECTION

The single day 24 consumer's consumption data and load on DT was monitored on site is shown in fig.1. The single day solar radiation and wind velocity data was measured on site. The horizontal radiations were converted into tilted surface using mathematical model to get real life result. The specification of oil-type 200 kVA DT and multi-crystalline PV module was collected from manufacturer. The DT temperature pattern was monitored for different consumers load condition. The rooftop area of the building connected to DT under study is considered for PV installation using PVsyst tool for installation estimation as per simulation requirement. Two installation results were considered as elevated 46.6kWp and non-elevated 37.8kWp structure. The fixed tilt installation is considered with inclination equal to latitude.i.e. 18.5°. The generated electrical unit was predicted for a day from the PV installation capacity.

3. HOTSPOT TEMPERATURE AND LOSS OF LIFE EVALUATION

3.1. Top Oil Temperature Equation

$$\theta_{TO} = \theta_A + \Delta\theta_{TO} \tag{1}$$

θ_{TO} is top-oil temperature in °C, θ_A is average ambient temperature in °C and $\Delta\theta_{TO}$ is top-oil rise over ambient temperature [8]. But there is significant effect of solar radiations and wind velocity on life of transformer as located outdoor. This effect on top oil temperature is given by equation (2).

$$\theta_{TO}[k] = K_1 \times \theta_{TO}[k-1] + K_4 \times \theta_A[k] + K_2 \times I[k]^2 + K_3 + K_5 \times S_{rad}[k] + K_6 \times V[k] \quad (2)$$

θ_{TO} is top-oil temperature in °C, θ_A is average ambient temperature in °C, I is load on transformer in kW, S_{rad} is global solar radiation W/m^2, V is wind velocity in m/s, k is iteration and K_1-$K_6$are coefficients for respective functions [16].

3.2. Hotspot Temperature Equation

Using top oil temperature calculated by equations (1) and (2), we can calculate hotspot temperature from equation,

$$\theta_H = \theta_H + \Delta\theta_H \quad (3)$$

θ_H is transformer hot-spot temperature in °C, $\Delta\theta_H$ is winding hottest-spot rise over top-oil temperature [8] and θ_{TO} is top oil temperature.

3.3. Transformer Loss of Life (LOL) Calculation

Percentage LOL of transformer for total time period t is given by,

$$\%LOL = \left(\frac{F_{EQA} \times t}{normal\ insulation\ life}\right) \times 100 \quad (4)$$

F_{EQA} is equivalent aging factor for the total time period, 't' [8].

4. DESCRIPTION OF MATLAB/SIMULINK MODEL

Using IEEE clause 7, the top oil temperature and hot spot temperature model has been calculated and simulated in Simulink model using equation (2). Load and ambient temperature data is saved in signal builder in the form of signal which are fed as an input to TOT model and it is feed as an input to HST model. Proposed systems Simulink model is as shown in Fig. 1. In this model the inputs as, solar radiation and wind velocity is also considered for more accurate results. Fig. 2 to 8 shows HST results obtained by calculation and compared by MATLAB model. Fig. 2 shows HST for the ambient temperature and load curve without considering any weather parameter. Fig. 3 shows HST considering solar radiation and wind velocity. Generally during day time solar radiation is more so HST increases. PV generation is considered as an input shown in Fig.4, which will reduce load on transformer so HST will be reduced. EVs are also considered in study which acts as an extra load on DTs. The two-wheeler is considered in Fig.5 and four-wheeler in Fig.6 shows increase in HST. Considering combination of PV with two-wheeler and four-wheeler is shown in Fig.7 and Fig.8, it is seen that PV compensates extra load due to EV. Fig. 9 and 10 shows impact due to weather parameters as solar radiation and wind velocity.

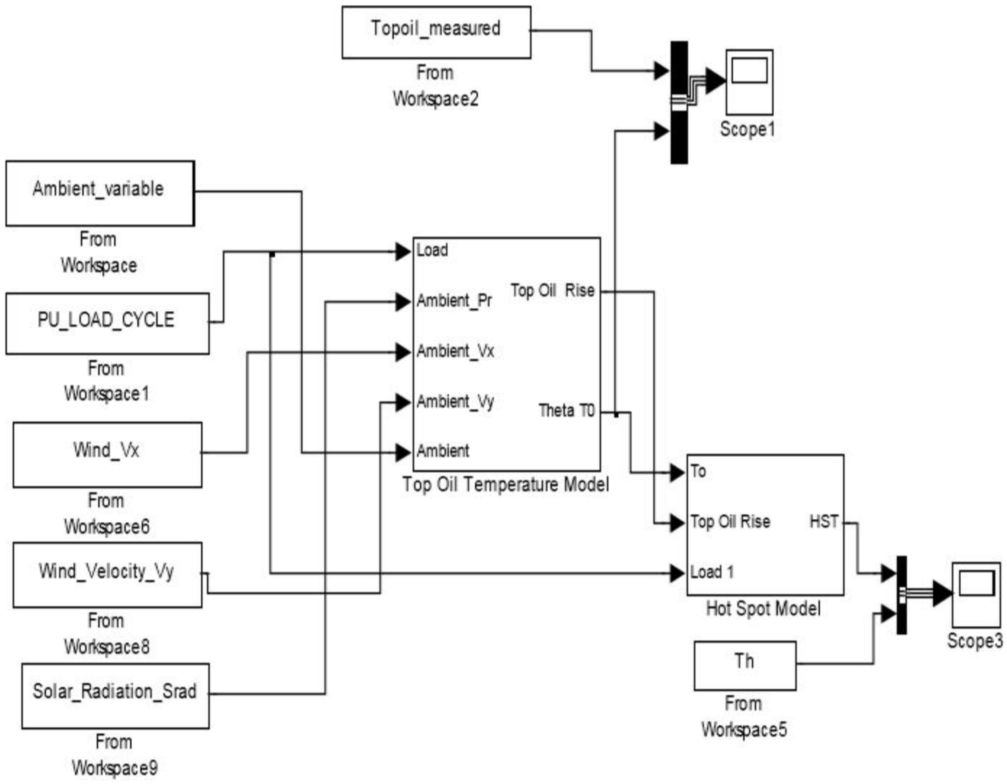

Figure 1 MATLAB/Simulink model

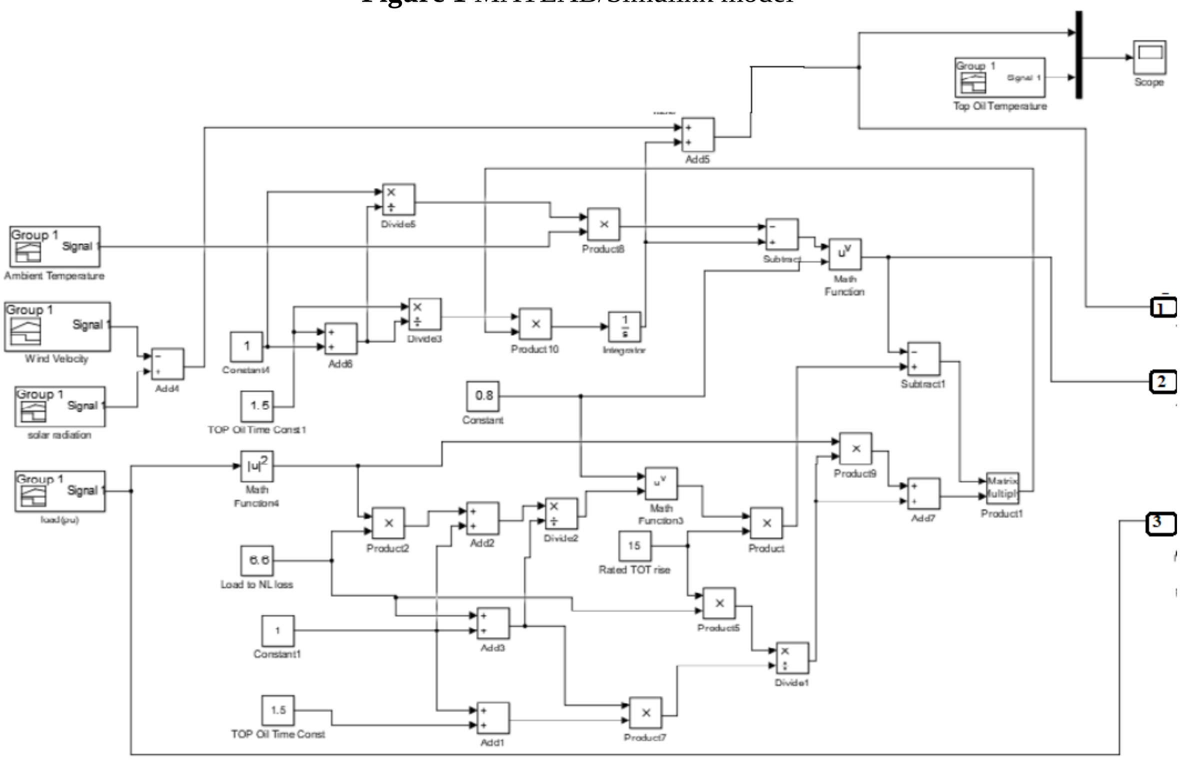

Figure 1(a). TOT rise Simulink model

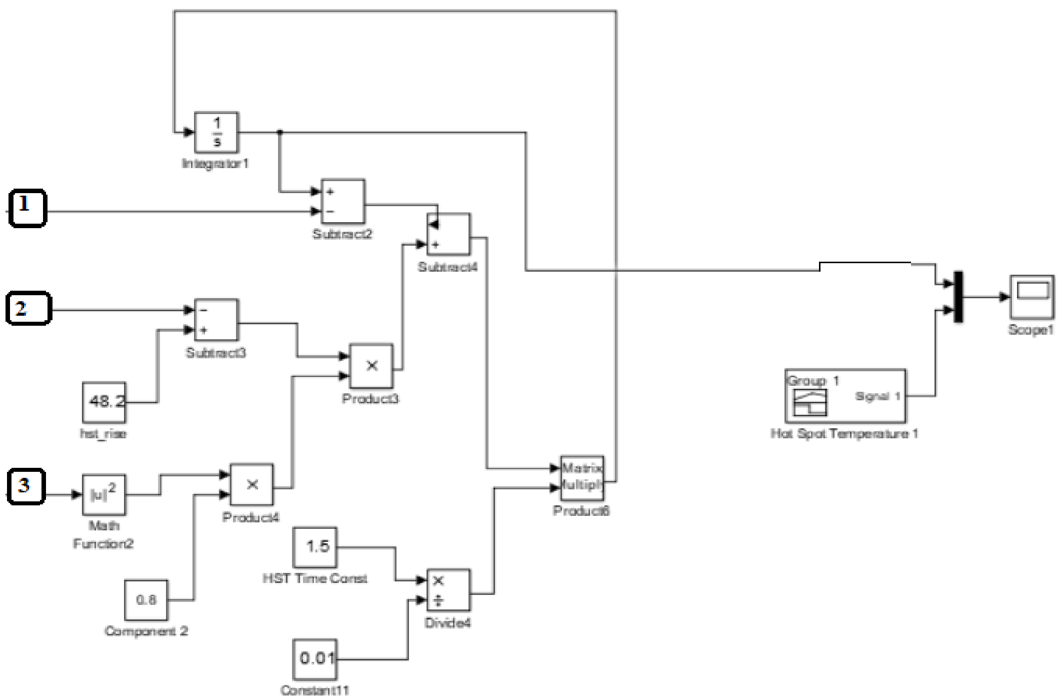

Figure 1(b). HST Simulink model

5. RESULTS AND DISCUSSIONS

The HST results obtained by calculation and compared by MATLAB model are shown in Fig. 2 to 8. The Fig. 2 shows HST for the ambient temperature and load curve without considering any weather parameter. The Fig. 3 shows HST by considering solar radiation and wind velocity. Generally during day time solar radiation is more so it HST increases. Further in addition to above parameters PV generation is considered in Fig.4. Addition of PV will reduce load on transformer so HST will be reduced. If PEV are considered then it acts as load on DTs. As two-wheeler considered in Fig.5 and four-wheeler in Fig.6 shows increase in HST. Considering PV with two-wheeler and four-wheeler as shown in Fig.7 and Fig.8, it is seen that PV compensates extra load of PEV. Fig. 9 and 10 shows input parameters as solar radiation and wind velocity. Fig. 11 and fig. 12 shows hourly consumption and generation pattern as well as gives comparison between residential load and PV generation for both elevated and non-elevated installations.

To calculate the total PV installation on building PVsyst software is used, as number of panels to be installed on roof-top has to be calculated. Total area of building for PV installation can be calculated, first by locating building and pinning the area on roof-top using Google earth, shown in Fig.13. Placing of panels graphically is done by using AutoCAD, it helps in calculate total number of panels on building.

The comparison of loss of life of transformer results showed in Table 1, in % and in hours by using analytical and Monte Carlo method for PV (100%) as well as PEV at 100%, 80%, 60%, 40% and 20% penetration for both elevated and non-elevated installations.

The hotspot temperature results shown in Table 2, for PV (100%) as well as PEV for 100%, 80%, 60%, 40% and 20% penetration for both elevated and non-elevated installations by implementing the Monte Carlo method**.** HST for elevated PV penetration is less compared to non-elevated as PV output for elevated PV penetration is more than non-elevated PV penetration.

The battery sizing using PSO method for PV elevated (47kWp) and non-elevated (38kWp) installations is shown in Table 3. For same module efficiency, area of panel, depth of discharge (DOD), efficiency of inverter, the PSO method gives better results for sizing of battery than analytical method.

Table 1 Loss of life of transformer results by Monte Carlo considering residential load, PV and different % values for EV

PV (elevated) = 46.62kW (100%), PV (non-elevated) = 37.8kW (100%) as well as EV (100%) = 23 Vehicles.

Resi.Load+PV+ EV	Loss of life (%) Elevated (* 10^{-6})	Loss of life (%) Non-elevated (* 10^{-6})	Loss of life (hrs) Elevated	Loss of life (hrs) Non-elevated
PEV (100%)	7.498	7.629	1.3497	1.3734
PEV (80%)	7.144	7.241	1.2860	1.3035
PEV (60%)	6.844	6.915	1.2320	1.2448
PEV (40%)	6.704	6.766	1.2068	1.2180
PEV (20%)	6.525	6.551	1.1746	1.1792
PEV (0%)	6.440	6.442	1.1594	1.1597

Table 2 Hotspot temperature of transformer by considering residential load, PV and different % values for EV

Time (24 Hours)	Resi. +PV +EV (100%)		Resi. +PV +PEV (80%)		Resi. +PV +PEV (60%)		Resi. +PV +PEV (40%)		Resi. +PV +PEV (20%)	
	Non-Elev.	Elev.	Non-Elev.	Elev.	Non-Elev.	Elev.	Non-Elev.	Elev.	Non-Elev.	Elev.
12:00 noon	43.42	43.42	43.28	43.28	43.17	43.17	43.06	43.06	43.01	43.01
1:00am	43.69	43.69	43.52	43.52	43.23	43.23	43.07	43.07	43	43
2:00am	44.09	44.09	43.79	43.79	43.41	43.41	43.07	43.07	42.89	42.89
3:00am	44.19	44.19	43.56	43.56	43.25	43.25	42.79	42.79	42.5	42.5
4:00am	45.11	45.11	44.62	44.62	43.81	43.81	43.39	43.39	43.11	43.11
5:00am	45.23	45.23	44.84	44.84	44.09	44.09	43.63	43.63	43.41	43.41
6:00am	44.47	44.47	43.89	43.89	43.27	43.27	43.06	43.06	42.8	42.8
7:00am	44.19	44.19	44	44	43.49	43.49	43.2	43.2	43.04	43.04
8:00am	42.61	42.56	42.38	42.33	41.91	41.87	41.55	41.51	41.26	41.23
9:00am	45.9	45.74	45.2	45.06	44.76	44.64	44.49	44.39	44.29	44.21
10:00am	47.65	47.43	47.1	46.93	46.7	46.58	46.49	46.41	46.41	46.35
11:00am	49.85	49.58	49.22	49.04	48.91	48.79	48.81	48.72	48.67	48.65
12:00 noon	51.32	51.05	50.8	50.63	50.65	50.52	50.58	50.47	50.41	50.41
1:00pm	52.74	52.43	52.29	52.04	52.05	51.84	52.03	51.83	51.57	51.48
2:00pm	53.25	52.97	52.87	52.65	52.6	52.43	52.53	52.38	52.22	52.19
3:00pm	53.93	53.72	53.61	53.42	53.22	53.09	53.15	53.03	52.88	52.82
4:00pm	53.27	53.16	52.98	52.89	52.6	52.53	52.51	52.45	52.34	52.29
5:00pm	52.91	52.84	52.5	52.44	52.12	52.08	52.03	51.99	51.89	51.86
6:00pm	52.09	52.05	51.68	51.65	51.32	51.3	51.11	51.09	50.8	50.78
7:00pm	50.27	50.27	50.08	50.08	49.8	49.8	49.47	49.47	49.15	49.15
8:00pm	48.18	48.18	48.01	48.01	47.92	47.92	47.82	47.82	47.55	47.55
9:00pm	46.67	46.67	46.58	46.58	46.5	46.5	46.4	46.4	46.22	46.22
10:00pm	44.88	44.88	44.88	44.88	44.88	44.88	44.88	44.88	44.88	44.88
11:00pm	43.65	43.65	43.65	43.65	43.65	43.65	43.65	43.65	43.65	43.65

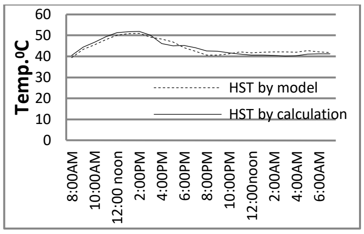

Fig 2. HST without solar & Wind

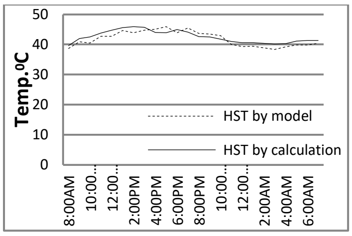

Fig 3. HST with solar & wind

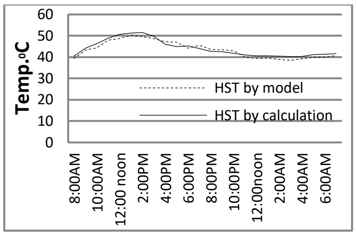

Fig 4. HST with solar, wind & PV

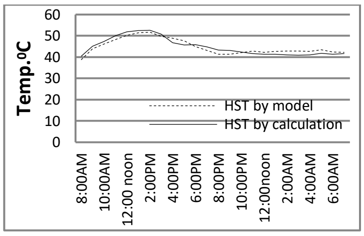

Fig 5. HST with solar, wind & PEV 2 wheeler

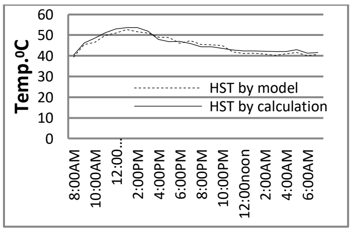

Fig 6. HST with solar, wind & PEV 4Wheeler

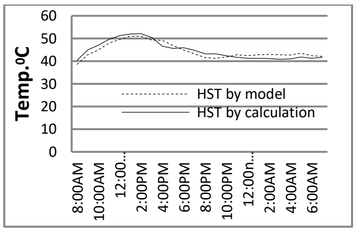

Fig 7. HST with solar, wind + PV+PEV 2 Wheeler

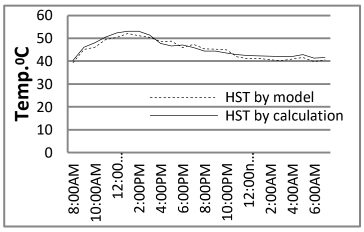

Fig 8. HST with solar, wind + PV+PEV 4 Wheeler

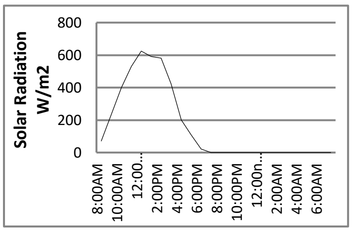

Fig 9. Solar Radiation (W/m^2)

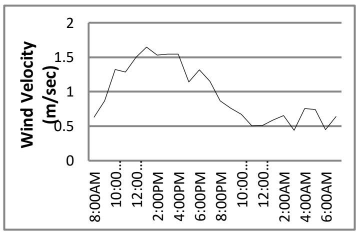

Fig 10. Wind Velocity (m/sec)

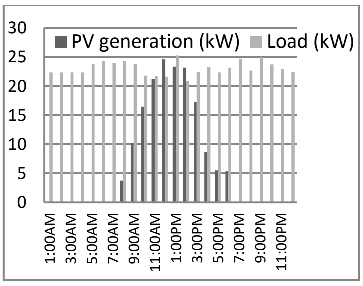

Fig 11. PV generation and load for Elevated installation

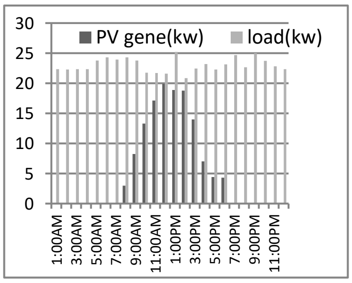

Fig 12. PV generation and load for Non-elevated

Fig 13. Building roof-top area under study

Table 3 Comparison of Battery sizing using analytical and PSO method

	38kWp Non-Elevated		47kWp Elevated	
	Analytical Method	**PSO Method**	**Analytical Method**	**PSO Method**
Module efficiency	0.1623	0.1623	0.1623	0.1623
Area	1.9404	1.9404	1.9404	1.9404
Battery size (kWh)	387.5541	386.5541	352.9075	350.9075
DOD	0.8	0.8	0.8	0.8
Efficiency of inverter	0.8	0.8	0.8	0.8
Battery size with DOD (kWh)	484.4427	483.4427	441.1344	439.1344
Battery size with DOD and inverter (kWh)	605.5583	604.5583	551.4180	549.4180

6. CONCLUSIONS

In this proposed work the impact of weather, solar PV roof-top and EVs are considered for obtaining realistic results while estimating percentage loss of life of 200kVA oil type transformer. A MATLAB model is used for estimation of TOT. A single day data of consumer's consumption, solar radiation, ambient temperature and wind velocity shared by authentic sources is considered in study. The calculated results of HST are compared and verified with MATLAB model and found satisfactory. Very important investigation is being extracted from the results that when EVs are considered the load on DT increases and its life decreases and when solar PV is considered as local generation the life of DT increases. Battery sizing solution for storage with one day's autonomy using PSO method is also suggested, as it increases the system stability.

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