Design and Analysis of an Off-Grid PV Plant for Higher Utilization Efficiency in The Field of Pharmaceutical Industry Considering Global Pandemic State

A.B.M. Khalid Hassan and Kazi Firoz Ahmed

Abstract—**According to the concern of WHO the less association of people in an office may restrict the likelihood of spreading this COVID-19 infection. On the other hand, the pharmaceutical companies are working hard to maintain uninterrupted production of vaccine and medicines. This paper focuses on the main layer which is the power system management and its utilization through automation and controlling remotely. In the design process the FDA (Food and Drug Administration) proposed structure and green energy solution is maintained. Solar energy utilization efficiency is increased using the data logging system and machine learning algorithms from archived data. A SCADA operated Off-Grid Solar PV Automation System has been proposed to increase the utilization efficiency. To predict solar power availability over time and perform efficient energy trafficking, the automation system will analyze previous data and perform situational awareness operations for uninterrupted solar power generation. A comprehensive analysis of the proposed automation system for pharmaceuticals industry applications has also been presented in this paper. The continuous monitoring system for this Off-Grid Solar PV power generating unit preserves multiple data entries, which increases with time and subjected to energy trafficking. And this energy trafficking based on machine learning increases the overall solar energy utilization efficiency from 64% to 99.92%.**

Index Terms—**SCADA, Automation, Solar PV, Energy Trafficking**

I. INTRODUCTION

IN pharmaceutical product manufacturing, an automation system in industry is evolving significantly over recent years [1]. The benefits are lower production cycle times, improved manufacturing efficiency, reduced rejects and increased production operating time [2].

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Beside production machineries process automation [3-4], water storage and distribution system, warehouse monitoring and control system, clean room automation, Building Management System (BMS), HVAC control system [5-9], etc. are also utilizing the benefits of automation for energy audit and energy saving options [10]. Roof top solar photovoltaic energy generation system is also being used in pharmaceutical industry applications over time [11-12] without any automation system combining PLC and SCADA for monitoring and control, data logging, energy trafficking or optimizing the overall energy utilization efficiency. Current studies and practices of installing a solar PV system is focused on energy generation efficiency by maximum power extraction with different MPPT algorithms, Sun Tracking and efficient energy conversion methods [13-17]. In this paper, an off-grid solar PV energy generation system has been designed for pharmaceutical industry application considering PLC and SCADA automation focusing on generated energy utilization efficiency. PLC and SCADA automation system is being widely used in solar power plants for monitoring and control, data logging, energy auditing, energy forecasting, distribution control and situational awareness [18-24]. That methodology has been considered to develop this proposed system which is specifically designed for pharmaceutical industry applications.

As all the pharmaceuticals manufacturing facilities are bound to maintain some guidelines of different regulatory authorities (Like, FDA 21 CFR Part 11, CE cGMP Annex 11, ISPE GAMP V, etc.) [25–27], they must have to ensure continuous power to their facility by installing online UPS system where inbuilt DC power storage is required. Most of the DC power storages are designed to provide backup for a minimum of 15 minutes to the respective load during a power failure. The off-grid solar PV system also requires inbuilt DC power storage for continuous power supply. The energy trafficking automation system allows us to use the DC power storage of online UPS systems directly with an off-grid solar PV system. The primary advantage of a supervisory control and data acquisition (SCADA) system is monitoring and control of any unit. Moreover, an automation system is capable of making adequate discissions based on available information. The reliability of an automated system is higher than manual systems. The user access level can be

controlled in a SCADA system, based on the user authority level of taking discissions. The audit trail of user activity, alarm and event logging, as well as trend data logging, are some basic features of any SCADA system. High-level data integration is an essential part of an automation system, where different components of the entire system containing different communication protocols (Like, BACnet, Modbus, LonTalk, PROFINET, etc.) can exchange data. Programmable logic controller (PLC) network is capable of directly controlling specific systems and read low-level data from any analogue or digital sensor throw its peripheral input and output interface. PLC network directly monitors and control the system in low-level and communicate with the SCADA system in high-level. In any pharmaceutical manufacturing facility, all the different units contain automation system. Process automation, building automation, industrial automation, etc. are being widely used in all pharmaceutical manufacturing facilities. Power system automation is widespread for large scale power generation plants and smart power grid applications. Low scale renewable energy generation units like off-grid rooftop solar PV systems are usually designed for outdoor lightings and unclassified area overhead lighting in most of the pharmaceuticals industry applications, due to unavailability of continuous solar irradiance and battery-based solution, the off-grid rooftop solar PV system usually not been used for classified areas of pharmaceutical manufacturing facilities. The reliability of the off-grid rooftop solar PV system can be optimized for classified areas of pharmaceutical manufacturing facilities with the power system automation.

The rest of the paper is organized as follows. In Section II, design overview of the proposed automation system, section III explains the operational process and analysis of the proposed automation system, section IV does the analysis of the overall system, section V is about feasibility study of the proposed system for pharmaceutical industry applications, section VI is about the result analysis and section VII is the conclusion.

II. AUTOMATION SYSTEM DESIGN

The proposed automation system contains a Programmable logic controller (PLC) network to monitor and control the solar plant field equipment and communicates with the SCADA server. Fig. 1 represents the system architecture of the entire automation system. The Energy Trafficking operation will be performed with the help of Supply Prediction and Load Forecasting.

The Supply Prediction will be performed by utilizing the available field data which will be collected and archived from the environment, solar PV panel and the DC power generation control unit. The possible data of these area are been discussed below.

A. Environmental Data

The Environmental Data Monitoring Unit will contain both satellite data for plant location and field sensor data from the plant. It continuously monitors Global Horizontal Irradiance (GHI, W/m2), the total irradiance received on a horizontal surface; Direct (Beam) Horizontal Irradiance (EBH, W/m2), the
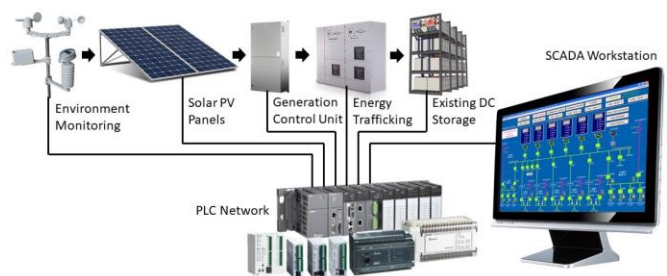

Fig. 1. System Architecture of the proposed Off-Grid Solar PV Automation System for Pharmaceutical Industry Applications.
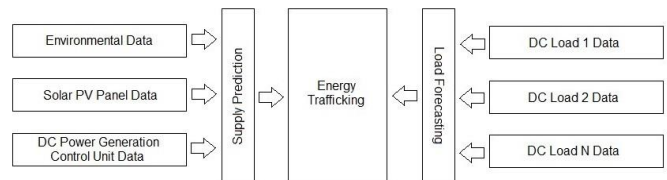

Fig. 2. Block Diagram of the Proposed Automation System of an Off-Grid Solar PV energy generation unit for Pharmaceutical Industry Applications.
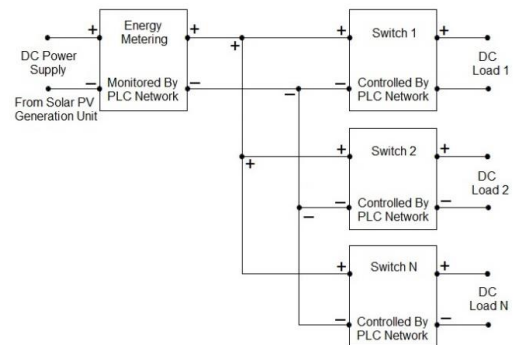

Fig. 3. Solar Energy Trafficking Unit Design of the proposed automation system.
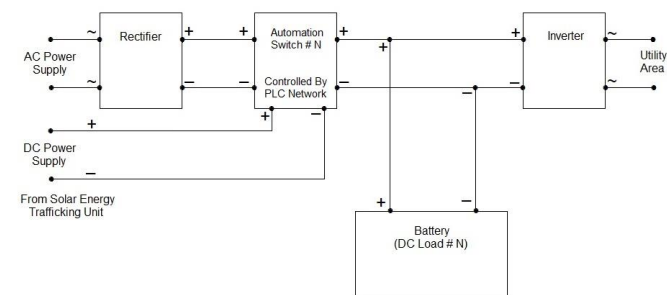

Fig. 4. Solar PV system generated DC power supply to the existing DC power storage unit of pharmaceutical manufacturing facility online UPS system.

horizontal component of Direct Normal Irradiance; Direct Normal Irradiance (DNI, W/m2), solar irradiance arriving in a direct line from the sun as measured on a surface held perpendicular to the sun; Diffuse Horizontal Irradiance (DIF, DHI, W/m2), the horizontal component of diffuse irradiance (irradiance that is scattered by the atmosphere); Temperature (TEMP, Celsius), the temperature of the air in the given location (10 meters above ground level); Solar Zenith (degrees), the angle between a line perpendicular to the earth's surface and the sun (90 deg = sunrise and sunset; 0 deg = sun directly overhead), Solar Azimuth (degrees), the angle between a line pointing due north to the sun's current position in the sky,

negative to the east, positive to the west, 0 at due north; Cloud Opacity (%), the measurement of how opaque the clouds are to solar radiation in the given location; Dewpoint (DWPT, Celsius), the air dewpoint temperature (2 meters above ground level); Relative Humidity (RH, %), the air relative humidity (2 meters above ground level); Surface Pressure (AP, hPa), the air pressure at ground level; Wind Speed (WS, m/s), the wind speed (10 meters above ground level); Wind Direction (WD, degrees), the wind direction (10 meters above ground level) where 0 is a northerly (from the north), 90 is an easterly (from the east), 180 is a southerly (from the south), 270 is a westerly (from the west); Precipitable Water (PWAT, kg/m2), the total column precipitable water content; Snow depth (SWDE, cm), the snow depth liquid-water-equivalent [28]; etc.

B. Solar PV Panel Data

In the solar PV panel unit, the monitored parameters include panel temperature monitoring, cleanliness monitoring, physical damage monitoring (like yellowing and browning, delamination, bubbles in the solar module, cracks in cells, defects in the anti-reflective coating, hot spots caused by the panel acting as a load [29], edge-seal delamination, newly cracked cells, delamination over cells and interconnections, split encapsulation over cells and interconnections, protruding interconnections [30], connections and the welds degradation [31], etc.), irradiance interruption monitoring, ambient light illuminance monitoring, etc.

C. DC Power Generation Control Unit Data

From the DC power generation unit, the monitoring data will be the generated DC voltage, current, power, etc. for individual modules, cable fault, array connection fault, combiner unit monitoring, MPPT unit monitoring, surge protector monitoring, earthing and lightning arrestor monitoring, switching devices monitoring, array junction box monitoring, power quality monitoring, disturbance fault analyzer monitoring, string combiner monitoring data, etc. This monitoring and control system is independent of any particular MPPT algorithms or other analyzing mechanisms. Each MPPT algorithms and other analyzing mechanisms will be monitored and controlled by this system with data logging and situational awareness options.

The energy trafficking unit will be directly controlled and monitored by the PLC network at low level peripheral I/O points. The automation system will decide the trafficking requirement based on supply prediction and load forecasting. The block diagram which gas been represented in Fig. 2 shows that both the load side and the generation side are connected with the energy trafficking process. The continuous monitoring of environmental data, solar PV panel data, DC power generation control unit data, etc. will be utilized for supply prediction. The existing DC power storage units of the running online UPS systems of the pharmaceutical manufacturing facility with be the DC Load of the automation system.

Load forecasting will be performed by utilizing all the load data which will be collected and archived from the existing DC power storages of online UPSs installed for the manufacturing facilities. In a large pharmaceutical product manufacturing facility, there are lots of different size of electrical loads which are been equipped with online UPSs. Among those, there are

Fig. 5. Supervisory Control and Data Acquisition (SCADA) Graphical User Interface (GUI) implementation.
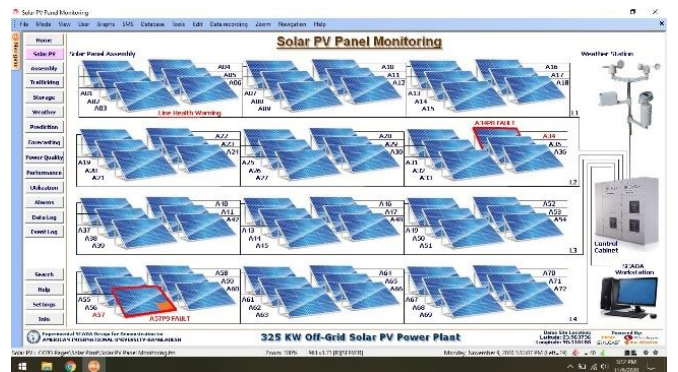

Fig. 6. Central solar panel monitoring page of SCADA GUI.

Fig. 7. Individual assembly monitoring page of SCADA GUI.
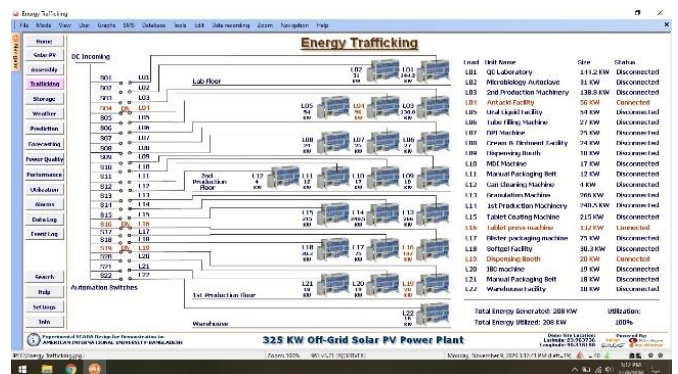

Fig. 8. Energy trafficking page of SCADA GUI.

some heavy loads like HVAC components as well as there are some small loads like plug loads of laboratory equipment. To connect with the proposed system, a single load must have to be smaller than the pick energy generation capacity of the solar

Fig. 9. DC power storage facility of existing online UPS monitoring page of SCADA GUI.
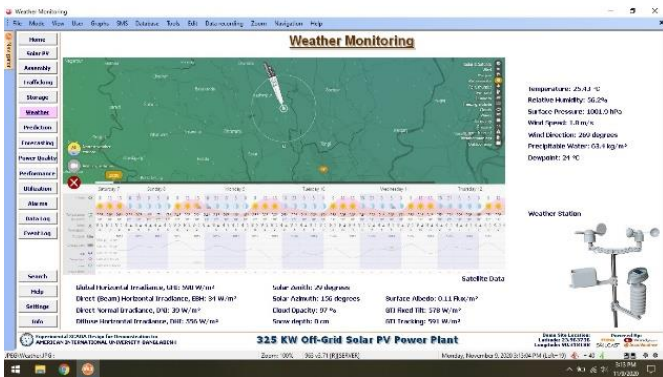

Fig. 10. Weather Monitoring Page of SCADA GUI.

PV unit. After connecting all the online UPS's battery banks of all possible loads with the proposed system through automation switches which will be controlled by the PLC network, the available parameters of the connected battery banks will be monitored and archived for load forecasting. The possible monitoring data of those DC power storage facilities like battery capacity, voltage level, current capacity, charging and discharging current and required time, input voltage and current, stored and supplies power, temperature, cooling unit data, failsafe/overload protection data, static bypass data, etc. will be utilized for load forecasting.

Solar energy trafficking unit design has been presented in Fig. 3. Here, all the connected DC energy storage unit will contain separate automation switch unit which will be controlled by the PLC network. The PLC network will connect the required loads with the DC power supply from solar PV energy generation unit based on the trafficking instruction of the automation system. Fig. 4 shows the process of supplying generated DC power to the storage unit. Inside the online UPS system, after converting the AC power from grid substation of generator, and before inverting into AC power again to supply to the load, the DC power storage unit are been connected. The automation switches will be connected in between the rectifier and the battery unit in this proposed system. As the battery unit will have direct connection with inverter, the load will get an uninterruptable power supply as before. The automation unit will measure the solar PV energy generation as well as the load requirements. Based on that information, the automation unit will decide either to connect or to disconnect the solar PV generated DC power with the battery and inverter unit. The detailed decision-making process has been discussed in the

process operation section. The automation switch will connect either rectifier power or Solar generated DC power to the battery and rectifier unit to ensure primary objective of utilizing 100% of Solar generated DC power.

The PLC network communicates with SCADA server, which is been used as the operator workstation for monitoring and control of the proposed solar system as well as database server. The graphical user interface of the SCADA system allows to monitor the running solar system, control different components, view historical data logs, alarm logs, event logs, user activity logs, audit trial logs, etc.

Fig. 5 to Fig. 9 represent some sample SCADA graphical user interface (GUI) pages of the proposed automation system. The PLC network communicates with SCADA server, which is been used as the operator workstation for monitoring and control of the proposed solar system as well as database server. The graphical user interface of the SCADA system allows to monitor the running solar system, control different components, view historical data logs, alarm logs, event logs, user activity logs, audit trial logs, etc. The Fig. 5 represents the home page of a roof-top 325 kW solar PV power plant which has been designed to monitor current amount of energy generation, energy utilization, and some basic weather monitoring data. Fig. 6 is the central solar panel monitoring page from where all the solar PV panel assembly will be monitored. When a panel fault or line fault will occur, the illustration representing that particular faulty component will show the alarm state visually on graphical user interface. To view the detailed parameters of any specific component, operator will click on that component illustration which will redirect to the component specific which loads are been currently connected and which loads are been currently disconnected can be monitored as well as override controlled if necessary. Fig. 9 and Fig. 10 are the DC power storage facility of existing online UPS monitoring page and weather monitoring data from both satellite and locally installed weather station respectively.

III. AUTOMATION PROCESS OPERATION AND ANALYSIS

After getting the supply prediction and load forecast, the automation unit will perform energy trafficking. This process operation can be considered as subset sum problem or bounded knapsack problem application. Considering the connectable load set which will be switched by the automation unit as L. The load set L has been shown in (1).

$$L = [L_1, L_2, L_3, \ldots \ldots \ldots, L_n] \tag{1}$$

Here, n = length(L) = 22 and L1 = 144.2 kW, L2 = 31 kW, L3 = 138.8 kW, L4 = 56 kW, L5 = 54 kW, L6 = 27 kW, L7 = 25 kW, L8 = 24 kW, L9 = 18 kW, L10 = 17 kW, L11 = 12 kW, L12 = 4 kW, L13 = 266 kW, L14 = 240.5 kW, L15 = 215 kW, L16 = 132 kW, L17 = 75 kW, L18 = 30.3 kW, L19 = 20 kW, L20 = 19 kW, L21 = 18 kW and L22 = 18 kW. Considered a function for the same number of α where α will be either 0 or 1 as shown in (2) and f(x) will contain n numbers of α as shown in (3).

$$f : \alpha \rightarrow \{0,1\}^n \tag{2}$$

$$x \rightarrow f(x) = (\alpha_1, \alpha_2, \alpha_3, \ldots \ldots, \alpha_n) \tag{3}$$

The function f(x) from (3) is to be determined by mixed-integer linear programming as some of the variables (Li) of the connectable load set L are constrained to be integers, while other variables are allowed to be non-integers [32]. Function f(x) will be used to find out the possible combinations of load set L, so that the error between the summation of output load set Lo and the generated energy G will be equal to or close to zero as shown in (4) and the amount of error will not be negative as shown in (5), because the summation of output load set Lo will never be more than the net solar PV generated energy.

$$\min \left(G - \sum_{i=1}^{n} \alpha_i L_i\right) \tag{4}$$

$$G - \sum \alpha_i L_i \geq 0 \tag{5}$$

Here, G = current energy generation (kW) = 0 ~ 325 kW, as this case has been analyzed for 325 kW peak capacity. The output of this process operation will provide the expected loads to be connected with the solar PV generated power to feed, by providing the output load set Lo which has been shown in (6).

$$L_o = (\alpha_1 L_1, \alpha_2 L_2, \alpha_3 L_3, \ldots \ldots, \alpha_n L_n) \tag{6}$$

By getting the value of α as 0 or 1, the process will decide the corresponding load will be kept or not in the output load set Lo. The simulation of this process operation provides different types of results for different values of G. As the value of G will change with time depending on weather condition and solar irradiation, for each and every value of G, there are lots of different output load combination Lo is possible. For example, when G = 208 kW, The MATLAB simulation provides different 226 possible combinations for Lo to be connected with the solar generated power G for exact zero error or 100% utilization of solar PV generated energy as shown in (7) or (8).

$$G - \sum \alpha_i L_i = 0 \tag{7}$$

$$\sum L_o = \sum \alpha_i L_i = G = 208 \tag{8}$$

The output Lo can be combined of different number of loads. Some sample of output combination Lo combining different number of loads from MATLAB [33] simulation have been presented in (9) to (13). Here, (9), (10), (11), (12) and (13) presents the possible combination with 3, 4, 5, 6 and 7 loads respectively.

$$L_o = (L_4, L_{16}, L_{19}) \tag{9}$$

$$L_o = (L_2, L_6, L_9, L_{16}) \tag{10}$$

$$L_o = (L_2, L_4, L_6, L_{17}, L_{20}) \tag{11}$$

TABLE I
L_O WITH ALL POSSIBLE COMBINATIONS OF 4 LOADS FOR G = 208 KW

Lo Load Sets				Lo Load Values (in kW)			
L_2	L_6	L_9	L_{16}	31	27	18	132
L_2	L_6	L_{16}	L_{21}	31	27	132	18
L_2	L_6	L_{16}	L_{22}	31	27	132	18
L_2	L_7	L_{16}	L_{19}	31	25	132	20
L_5	L_9	L_{12}	L_{16}	54	18	4	132
L_5	L_{12}	L_{16}	L_{21}	54	4	132	18
L_5	L_{12}	L_{16}	L_{22}	54	4	132	18
L_6	L_7	L_8	L_{16}	27	25	24	132

TABLE II
VALUES OF G WITH ERRORS FOR 1 KW SAMPLE STEPS

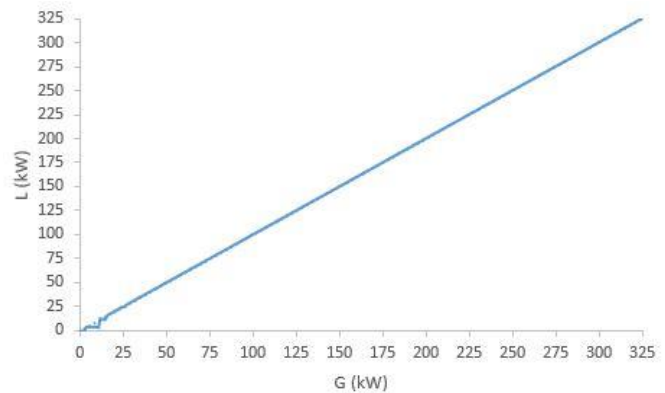| G	Lo	Error	Utilization	Wastage
1 KW	0 KW	1.00 KW	0 %	100 %
2 KW	0 KW	2.00 KW	0 %	100 %
3 KW	0 KW	3.00 KW	0 %	100 %
5 KW	4 KW	1.00 KW	80 %	20 %
6 KW	4 KW	2.00 KW	66.67 %	33.33 %
7 KW	4 KW	3.00 KW	57.14 %	42.86 %
8 KW	4 KW	4.00 KW	50 %	50 %
9 KW	4 KW	5.00 KW	44.44 %	55.56 %
10 KW	4 KW	6.00 KW	40 %	60 %
11 KW	4 KW	7.00 KW	36.36 %	63.64 %
13 KW	12 KW	1.00 KW	92.31 %	7.69 %
14 KW	12 KW	2.00 KW	85.71 %	14.29 %
15 KW	12 KW	3.00 KW	80 %	20 %
26 KW	25 KW	1.00 KW	96.15 %	3.85 %

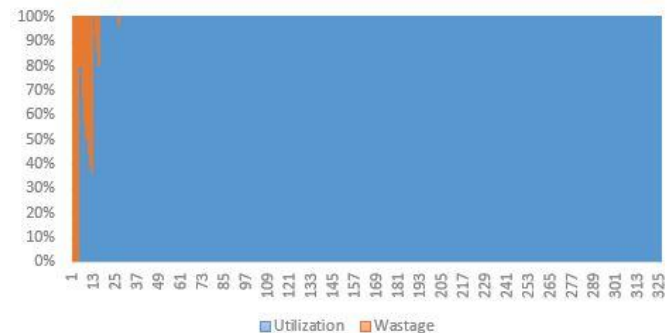Fig. 11. Graph of MATLAB simulation result for G = 0 ~ 325 kW with 1 kW sample steps.

Fig. 12. Energy Utilization and Wastage.
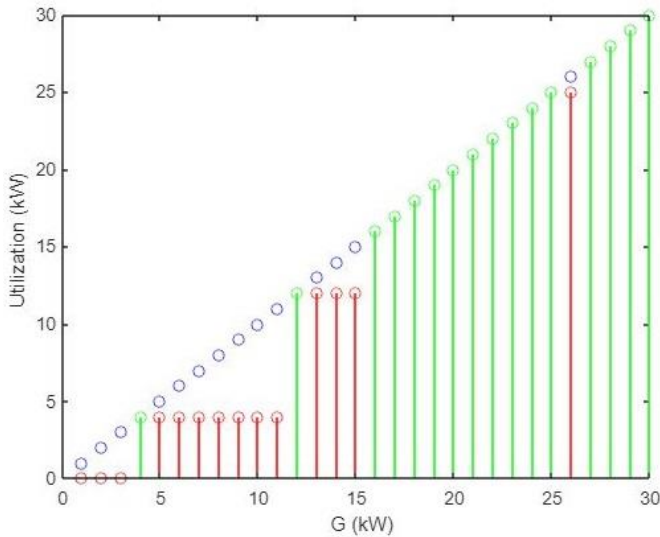
$$L_o = (L_2, L_4, L_5, L_7, L_8, L_9) \tag{12}$$

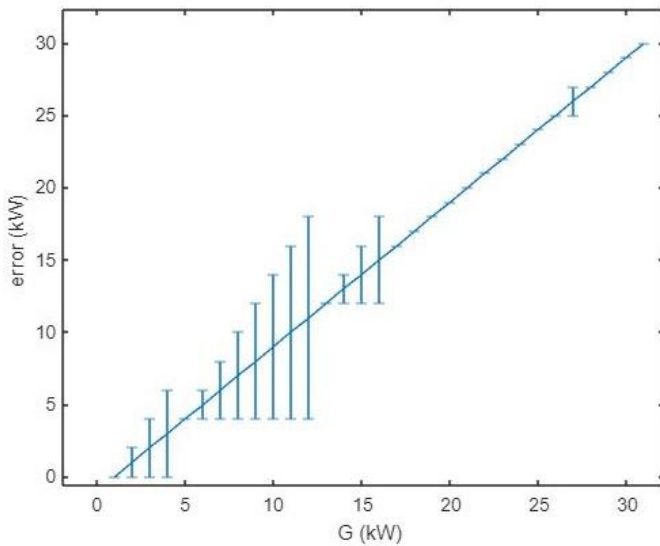Fig. 13. Energy Utilization MATLAB simulation result for G = 0 ~ 30 kW with for 1 kW sample steps.

Fig. 14. Error or Energy Wastage MATLAB simulation result for G = 0 ~ 30 kW with for 1 kW sample steps.

$$L_o = (L_2, L_4, L_5, L_6, L_8, L_{11}, L_{12}) \tag{13}$$

The summation of load set Lo is exactly equal to G=208 which has been presented in (14), (15), (16), (17) and (18) for (9), (10), (11), (12) and (13) respectively.

$$\sum L_o = 56 + 132 + 20 = 208 = G \tag{14}$$

$$\sum L_o = 31 + 27 + 18 + 132 = 208 = G \tag{15}$$

$$\sum L_o = 31 + 56 + 27 + 75 + 19 = 208 = G \tag{16}$$

$$\sum L_o = 31 + 56 + 54 + 25 + 24 + 18 = 208 = G \tag{17}$$

$$\sum L_o = 31 + 56 + 54 + 27 + 24 + 12 + 4 = 208 = G \tag{18}$$

100% utilization of solar PV generated energy with any specific number of loads to be connected, also possible with

Fig. 15. Solcast simulation results of supply prediction showing live and forecasts for 3 days.

Fig. 16. Solcast simulation results of supply prediction showing accuracy report for 7 days.
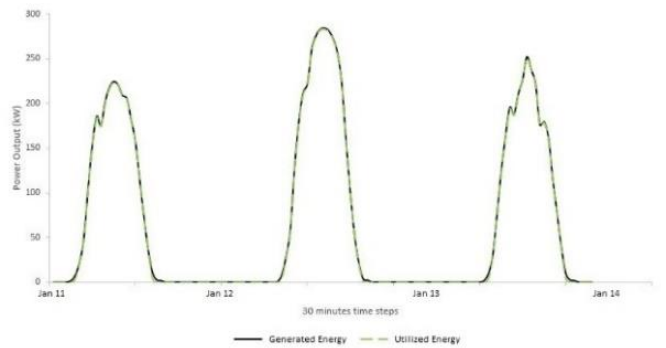

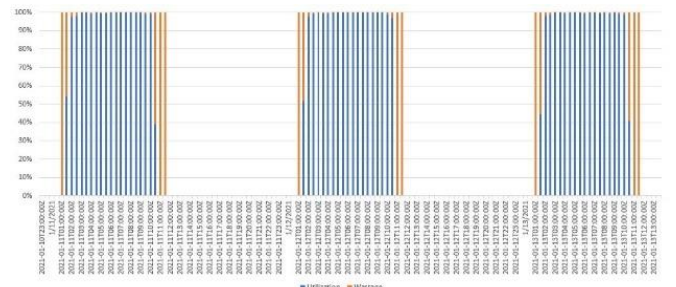Fig. 17. MATLAB simulation for Solcast data showing Generated Energy and Utilized Energy.

Fig. 18. MATLAB simulation for Solcast data showing Energy Utilization and Wastage analysis.

different combinations. Like, for total 4 loads, there are 8 different combinations are possible with exact zero error, which

has been shown in Table 1. As the 100% solar PV generated power utilization is possible with more than one combination for G = 209 kW as shown in Table 1, the automation unit will utilize this flexibility to select the loads based on the load forecasting data. The MATLAB simulation result for 1 kW sample steps shows that, the 100% utilization is possible for every single value of G with the existing 22 loads, when the value of G is higher than 26 kW. The Fig. 11 is the graph of the total utilized energy, L with respect to the total generated energy, G, which shows that the 100% utilization is not possible only for the low generation of power from solar PV unit. Fig. 12 shows the percentage of total energy utilization and total energy wastage for G = 0 ~ 325 kW in 1 kW sample steps.

When the total generated energy is below 27 kW, energy wastage will occur for total 14 cases. Those are G = 1 kW, 2 kW, 3 kW, 5 kW, 6 kW, 7 kW, 8 kW, 9 kW, 10 kW, 11 kW, 13 kW, 14 kW, 15 kW, and 26 kW. Here, the highest amount of error or energy wastage will occur for G = 11 kW which is error = 7 kW and, the lowest amount of error or energy wastage will occur for G = 1 kW, 5 kW, 13 kW, and 26 kW which is error = 1 kW. The MATLAB simulation result for G = 0 ~ 30 kW, where for G = 4 kW, 12 kW, 16 kW, 17 kW, 18 kW, 19 kW, 20 kW, 21 kW, 22 kW, 23 kW, 24 kW, 25 kW, 27 kW, 28 kW, 29 kW, and 30 kW, the 100% energy utilization is possible with the considered load set, and for the other values of G, the 100% utilization is not possible, which has been presented in Fig. 13. The error bar graph has been shown in Fig. 14. All the values of G with errors have been presented in Table 2 with their most optimized load combinations for achieving the lowest amount of error as found by MATLAB software [33] and their total amount of utilized and wasted energy with the percentage of energy utilization and wastage for 1 kW sample steps.

Appling MATLAB simulation result for Solcast API Toolkit [34] simulation data for a demo location of Latitude: 23.963733 and Longitude: 90.318134 rooftop solar PV site with 325 kW peak capacity, south facing azimuth 180 degrees, horizontal tilt 23 degrees, a real time scenario can be analyzed. Fig. 15 and Fig. 16 represents the Solcast simulation results of supply prediction, where Fig. 15 presents the live power output (for the date of January 14 of 2021), actual power output for last 3 days (from January 11 of 2021 to January 13 of 2021), and the predicted power output for next 3 days (from January 16 of 2021 to January 16 of 2021) with 90/10 probability.

Fig. 16 presents the supply prediction accuracy for last 7 days (from January 7 of 2021 to January 13 of 2021). The live and forecasts graph of Fig. 15 shows 3 hours ahead supply prediction forecasts and the 7 days accuracy report of Fig. 16 has been generated for 1 hour ahead supply prediction forecasts. Fig. 17 and Fig. 18 represents the MATLAB simulation results for Solcast simulation data. Fig. 17 shows the total generated energy and the total utilized energy of the roof top solar PV system, where it can be seen that total utilized energy line almost follows the total generated energy line. At the morning and evening, when the energy generation is relatively low, their might have some wastage. From the simulated result maximum amount of wasted energy in last 3 days (from January 11 of 2021 to January 13 of 2021) was 6.2543 kW at the evening of 11 January, 2021 when the value of G was 10.2543 kW. So, the
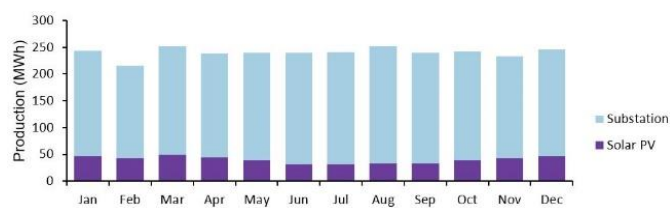

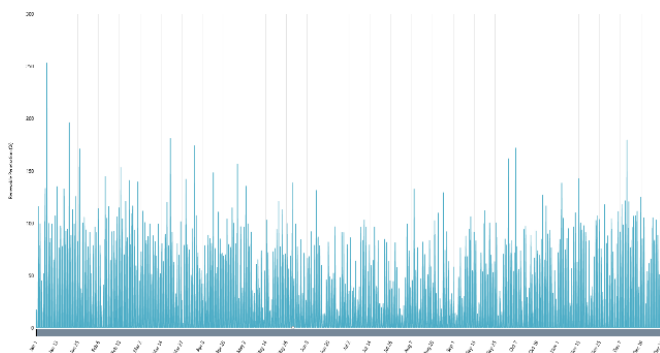Fig. 19. Annual power generation from solar PV system and utilization of grid power.

Fig. 20. Homer software renewable penetration analysis data of the proposed system.
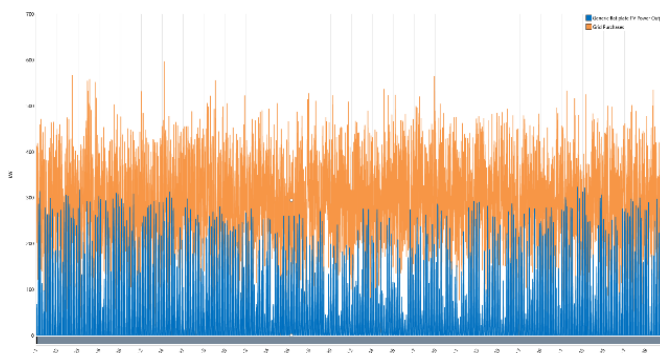
Fig. 21. Homer software energy utilization analysis simulation data showing annual data.
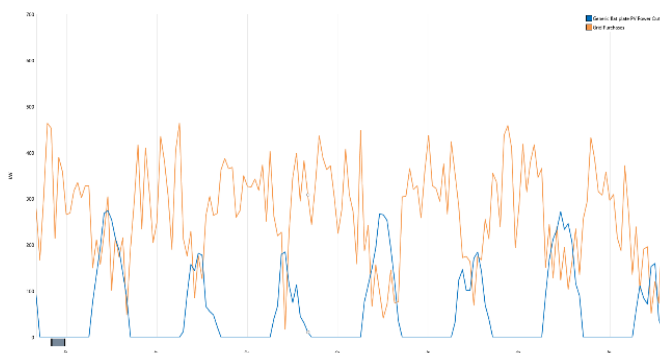
Fig. 22. Homer software energy utilization analysis simulation data showing everyday scenario.

39.0080259% generates energy has been utilized and 60.9919741% generates energy has been wasted at evening time. The minimum amount of wasted energy was 0.0026 kW at the mid-day of 13 January, 2021 when the value of G was 237.3026 kW. So, the 99.99890435% generates energy has been utilized which is equivalent to 100% and 0.001095647% generates energy has been wasted which is equivalent to 0% at mid-day. Everyday, at morning and evening time, the solar PV energy generation remains below 4 kW. At that time, the 100%

generated energy had been wasted as there is no load sized under 4 kW in the considered load set. Fig. 18 represents the energy wastage in the morning and evening times and the almost 100% utilization in the mid-day.

IV. OVERALL SYSTEM ANALYSIS

In all pharmaceutical manufacturing facilities, to ensure the acceptance of end products all over the world, the compliance with some international regulatory authority guidelines is been ensured. As a result, all existing facilities are utilizing online UPS system to ensure the uninterruptable power to production machineries. Utilizing the existing DC power storage units from those online UPS systems, a large amount of solar PV system installation cost can be reduced. In that case, a sophisticated energy trafficking system will be required which will be performed by the proposed automation system to ensure the reliability. The basic system to feed the pharmaceutical manufacturing facility loads combining the grid power and backup generator. Here the problem is, at the time of load shedding from the grid power, the backup generator takes a startup delay for about 5~10 minutes on average. So, the uninterruptable power supply to the load is not possible. As it is a core requirement of most of the international regulatory authority guidelines to maintain the uninterruptable power supply to the load, all pharmaceutical manufacturing facilities contain online UPS system with at least one hour power backup capacity. The traditional hybrid system includes solar PV energy generation system containing in-built DC power storage system for at least 3 days power backup capacity. In this traditional hybrid system, the total load of the manufacturing machineries can be operated using renewable power if any major climate constrains does not occur. For worst case scenario, both the grid power and the backup generator power can be utilized to maintain the uninterruptable power supply to the load. The addressed limitation here is the installation cost of the in-built DC power storage system for solar PV system which is high. This limitation can be overcome by utilizing the existing DC storage units of online UPS directly for solar PV unit generated DC power. In that case an efficient energy trafficking system will be required to ensure the 100% utilization of solar PV generated renewable power, which will be performed by the proposed automation system as discussed in the previous section.

The proposed hybrid system renewable penetration analysis has been presented in Fig. 19 and Fig. 20. Fig. 19 is the total energy supplied to the considered pharmaceuticals industry manufacturing facility loads where the fully utilized total energy generation from the 325 kW off-grid solar PV unit as well as the total amount of energy utilization from grid which was required by the production machineries load for each month of a sample year inside the considered lifetime of the proposed hybrid system. Fig. 20 shows the percentage of renewable penetration throughout the year which is the ratio between the total renewable electrical power output of the renewable source in kW and the total electrical load served in kW for each time step.

The simulation result shows the maximum value of renewable penetration that occurs during the year. In Fig. 21,

TABLE III
TYPICAL PHARMACEUTICALS MANUFACTURING FACILITY LOAD DISTRIBUTION

	Overall	Plug Loads and Processes	Lighting	Heating, Ventilation and Air Conditioning
Total	100%	25%	10%	65%
Laboratory Environment	30%	Microscopes, Centrifuges, Electric Mixers, Analysis Equipment, Sterilization Processes, Incubators	Task and Overhead Lighting	Clean Rooms, Fume Hoods, AHU, MAU, Chilled Water System, Hot Water System
Comfort Zone	10%	Office Equipment	Task, Overhead and Outdoor Lighting	Space Heating, Cooling, Ventilation
Bulk Manufacturing Area	35%	Incubators, Sterilization Processes, Centrifuges, Dryers, Separation Processes	Task and Overhead Lighting	Clean Rooms, Fume Hoods, AHU, MAU, Chilled Water System, Hot Water System and Steam System
Formulation, Packaging and Filling Area	15%	Mixers, Motors	Mostly Overhead, Some Task	Particle Control Ventilation
Warehouses	5%	Forklift, Water Heating	Mostly Overhead Lighting	Space Heating, Refrigeration
Miscellaneous	5%			

the Homer software simulation data for energy utilization analysis has been presented where both renewable power generation from 325 kW off-grid solar PV unit and energy utilization from grid has been showed. Fig. 22 is the annual data for one sample year inside the considered lifetime of the proposed hybrid system which is 25 years. Fig. 22 shows the everyday scenario for some sample days from the month of January, which presents that at the time of utilizing the renewable power, the grid power utilization decreases as required by the load. The system analysis simulations work has been performed with Homer software [35] which applies NASA prediction of Worldwide Energy Resource (POWER) database for solar Global Horizontal Irradiance (GHI) and Clearness Index to simulate the probable solar PV energy generation throughout the year at the considered demo location of Latitude: 23.963733 and Longitude: 90.318134 rooftop solar PV site. The ideal parameters have been used for all simulation as suggested by Homer software. As the total amount of the considered facility load which is connected with the proposed hybrid system is higher than the peak capacity of the renewable source which is 325 kW most of the time for this considered test scenario, the pharmaceutical facility is taking the grid power after utilizing 100% of the renewable power most of the time.

V. Feasibility Study for Pharmaceuticals

A typical load distribution scenario in a pharmaceutical industry has been presented in Table 3 [36]. From Table 3, it has been presented that, in a pharmaceutical industry, most of the electrical power is been used for Heating, Ventilation and Air Conditioning (HVAC) applications which is 65% of the total load. HVAC system maintains the environmental parameters like temperature, relative humidity, differential air pressure, air filtration etc. in the classified clean room environment of the pharma manufacturing areas. No online UPSs are been used with these HVAC loads as the environmental parameters cannot be changed instantly after the power failure at the time of load shedding from the grid. The central backup generators are been assigned to start automatically within few minutes and the HVAC equipment starts operating as soon as the backup power is stablished. In these few minutes, the environmental parameters do not go out of limit for most of the cases. Though, the automation unit of HVAC control system which is known as building management system (BMS), contains their own online UPS system which is very low in size with respect to other HVAC loads. In some cases, the HVAC loads are been required to be run uninterruptedly due to the sensitive product requirements. For those cases, all the high loads of HVAC equipment also contain online UPS system. 10% of the overall load is been required for lighting purpose, which also do not require any online UPSs. Few emergency lights in each area contains online UPS service in pharmaceuticals industry. Plug loads and processes consumes 25% of the total load. In this section, some loads which are in comfort zones, warehouses and miscellaneous areas, do not require online UPSs in most of the pharmaceutical industry applications. The laboratory environment, bulk, manufacturing area, formulation, packaging and filling areas are very important and sensitive areas in any pharma industry, where each pharma maintains the 100% uninterrupted power supply utilizing online UPS systems.

All the pharmaceutical manufacturing facilities are been located in commercial zone where the availability of space for installing a solar PV energy generation system is low. Even, the roof top areas are also been occupied for chiller plant, cooling towers, helipads, etc. The rest of the area can be utilized for generating solar power, but in that case the total size of the solar power plant will not be enough for feeding the total loads of a pharmaceuticals manufacturing facility. In that case, the utilization of grid power is the most feasible option. The backup generator is required to supply power to the load at the time of load shedding from the grid. Due to the weather dependency of solar PV power generation system, a DC power storage facility is required to ensure the reliability which involves additional space, cost and operational maintenance issues. As, all the online UPS systems for important and sensitive plug loads and processes already contains DC power storage facilities, utilizing those facilities decreases the installation cost of a solar PV power generation system by reducing the cost of DC power storage unit to zero. In that case, all the facility loads which are equal or less than the rated capacity of the solar PV system needs to be connected to the solar PV system through a sophisticated automation system which will perform efficient energy trafficking to maintain the 100% utilization of

|	Morning	Mid-day	Evening
Generated Energy	21.46 kW	224.17 kW	35.29 kW
Utilized Energy with Energy Trafficking	21.00 kW	224.00 kW	35.00 kW
Utilized Energy without Energy Trafficking	0.00 kW	144.20 kW	0.00 kW
Error with Energy Trafficking	0.46 kW	0.17 kW	0.29 kW
Error without Energy Trafficking	21.46 kW	79.97 kW	35.29 kW
Utilization with Energy Trafficking	97.85 %	99.92 %	99.19 %
Utilization without Energy Trafficking	0.00 %	64.33 %	0.00 %
Wastage with Energy Trafficking	2.16 %	0.08 %	0.81 %
Wastage without Energy Trafficking	100.00 %	35.68 %	100.00 %
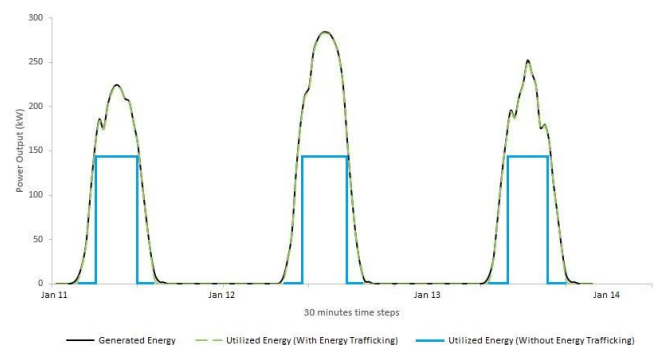
Fig. 23. Comparison between Utilized Energy with Energy Trafficking and Utilized Energy without Energy Trafficking with respect to the Total Generated Energy.
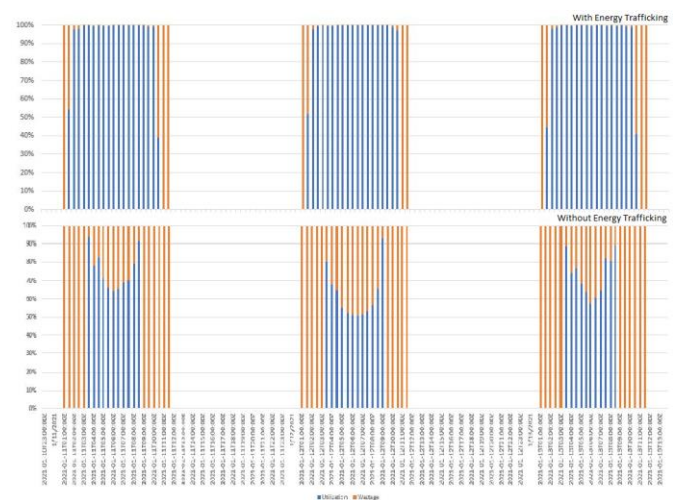
Fig. 24. Comparison of Energy Utilization and Wastage between the two systems where one is with Energy Trafficking and another one is without Energy Trafficking.

renewable power and ensure the reliability. The installation of this proposed system includes a comparatively high installation cost, but it will be cost efficient considering the full lifecycle of the project as it will help to reduce the purchase of grid power over time.

VI. RESULT ANALYSIS

The considered 325 kW solar PV system is unable to produce electricity up to its full capacity throughout the year due to weather dependency. In the considered load set of pharmaceuticals manufacturing facility contains a maximum load size of 266 kW, but based on the Global Horizontal Irradiance (GHI) data from both Solcast and NASA prediction of worldwide energy resource reflects that the generated energy from a 325 kW solar PV system in the considered location will be under 266 kW in most of the time. Considering the highest load below 200 kW to be connected with the solar PV system which is 144.2 kW as a traditional fixed load renewable energy system, the comparison between the proposed hybrid renewable energy system with energy trafficking and the traditional hybrid renewable energy system with fixed load or without energy trafficking has been presented in Table 4 as well as Fig. 23 and Fig. 24.

Comparing the fixed load system with the Solcast, MATLAB and Homer simulation data of the proposed system, it can be seen that the generated energy will be utilized only when the value of the generated energy will be greater than the value of the connected load size, as the in-built DC storage facility has been excluded in this scenario for cost minimization. Table 4 shows that at the sample time in morning, when the amount of the generated energy is 21.46 kW, the proposed system has already started utilizing the solar PV generated energy and the percentage of utilization is already 97.84462%, but the fixed load system has not started utilizing the solar PV generated energy as the value of the generated energy is still less than the connected load value. At a sample time in mid-day, when the solar PV generated energy is 224.17 kW which is higher than the load size of the fixed load system, both of the system has started utilizing the solar PV generated energy. But, the utilized energy of the proposed system is 224.00 kW which is a 99.92283% utilization where the utilized energy of the fixed load system is still same as the connected load size 144.2 kW which is only 64.32532% utilization. At a sample time in evening, when the amount of the generated energy is again decreased to 35.29 kW, the proposed system is still utilizing the solar PV generated energy and the percentage of utilization is 99.18836%, but the fixed load system has already stopped utilizing the solar PV generated energy as the value of the generated energy is again less than the connected load value.

The graph of Fig. 23 presents the comparison between utilized energy with energy trafficking and utilized energy without energy trafficking with respect to the total generated energy, which shows that the energy wastage of fixed load system is always higher than the energy wastage of proposed system which also reflects the sample data presented in Table 4. Fig. 23 also presents that when the generated energy is higher than the fixed load value, the utilized energy is always equal to the fixed load value and the extra amount of generated energy is been wasted. But for the proposed system, the energy wastage is always low. Fig.24 presents the comparison of the percentage of Energy Utilization between the two systems where one is with Energy Trafficking and another one is without Energy Trafficking. It also presents that the solar PV generated electricity utilization is always higher in the proposed system than the fixed value system. The solar PV generated electricity wastage is also less in the proposed system than the fixed value system.

There are some added advantages of utilizing and automation system for an off-grid solar PV energy generation unit in pharmaceutical industry applications. An automation system can perform all the required activities with a zero to minimum supervision. It also contains all the required features for international pharmaceuticals regulations as continuous monitoring and data archiving is required to comply with international regulations. A pharmaceutical manufacturing facility must have to be ensured by 100% uninterrupted power supply. Frequent shifting of power sources is not acceptable in a validated pharmaceuticals environment. Combined operation of solar generated DC power and incoming AC power inside an online UPS system will have no effect of load side. The Load will have 100% uninterrupted power supply as before after utilizing solar power. In this way, most of the solar generated power can be utilized. Sophisticated energy supply prediction and load demand prediction based on archived historical data on both generation end and load end can be used for ensuring reliability. As each and every pharmaceuticals industry contains online UPS system for most of its critical units, if the battery bank of those online UPSs can directly be utilized for storing solar power and feeding critical loads, it will be both cost efficient and almost 100% solar generated power can be utilized.

VII. CONCLUSION

From the analysis it has been observed that the utilization of solar PV generated energy is better in the proposed system for pharmaceutical company than a traditional integrated renewable energy system. In most of the traditional integrated renewable energy system, the load set usually been shifted to different energy sources based on the availability of the electrical energy in different sources like renewable, generator, or grid power. In that case, when the generated energy by the renewable sources is less than the connected load set, the load set is shifted to another source based on priority. As a result, the generated energy of the renewable sources though it is low is wasted. From the simulation it is shown that the load side management can help to utilize the produced energy efficiently. At the morning and evening time, when the net amount of solar PV generated energy is less than the traditional fixed load system, the 100% solar PV generated energy will be wasted, but the energy wastage is reduced to 2.16% in the morning and 0.81% in the evening with the proposed system for the given sample time as the automation unit is performing the load side management automatically. During this Covid-19 Pandemic it is very important to go for automation with high efficiency in load management. In the mid-day, when the net amount of solar PV generated energy is more than the traditional fixed load system, the total utilized energy will be equal to the value of the fixed load set. As a result, all the excess solar PV generated energy will be wasted. For example, for a given sample time of mid-day, when the energy utilization by the traditional fixed load system without energy trafficking is 64.33%, the utilization is increased up to 99.92% with the proposed system where the energy trafficking is automated by an automation unit to perform the load side management. All the given data which

have been presented in this paper for the considered test case scenario shows that the solar PV generated energy utilization can be maximized or the energy wastage can be minimized by the proposed system.

In the traditional fixed load system, to utilize the excess solar PV generated energy which is not utilized by the connected load instantly, can be used later with the help of a DC power storage facility. In that case, the maximum utilization of solar PV generated energy can be utilized with the help of a considerably large size of battery bank which involves a significant amount of cost, area and maintenance issues. Moreover, though a very large size of battery bank can increase the solar PV generated energy utilization up to 100%, the 100% utilization of the installed battery bank cannot be possible throw out the year due to weather dependency. As a result, an economic design cannot be possible for the integrated renewable energy system in this way. To increase the cost efficiency, the size of the DC storage unit must be minimized to a point where the cost to utilization ratio will be at the lowest value. In that case, the 100% of solar PV generated energy utilization will not be possible.

Moreover, the DC power storage facility installation has been excluded from the proposed system as almost 100% solar PV energy utilization can be possible with the help of an automation system including the added advantages of an automation system like SCADA graphical user interfaces, data archiving, complying with all the guidelines of international regulatory authorities for pharmaceutical industries. As a result, the installation cost, area requirement, and maintenance issues will be no longer required for the DC power storage facility in the proposed system. To maintain the continuous power to the critical pharmaceutical machineries at the time of load shifting or energy trafficking, integrating the solar PV generated DC power with the existing online UPS system battery bank will ensure the reliability. Considering all the above stated cases, it shows that the proposed system will be more beneficial than the traditional integrated renewable power system for pharmaceuticals industry applications.

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