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A Real Time Comparison of Standalone and Grid Connected Solar Photovoltaic Generation Systems

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***Abstract*—**Green and renewable energy is getting extraordinary consideration today, because of ecological concerns made by blazing of fossil powers. Photovoltaic and wind power generation are the basic decisions for delivering power in this respects. Producing power by the sun based photovoltaic systems is known to the world, yet control makers may get confounded to pick between on-grid and off-grid systems. In this exploration work, an endeavor is made to compare the off-grid (stand-alone) and on-grid (grid-connected) frameworks. The work presents relative examination, between two distinctive PV frameworks situated at V.V.P. Engineering College, Rajkot. The first framework is 100 kW remain solitary and the second is 60 kW network joined. The real-time parameters compared are; output voltage, load current, power in-flow, power output, performance ratio, yield factor, and capacity factor. The voltage changes and the power variances in both frameworks are given exceptional consideration and the examination is made between the two frameworks to judge the focal points and confinements of both the frameworks.

***Keywords*—**Standalone PV systems, grid connected PV systems, comparison, real time data analysis.

I. INTRODUCTION

WITH the approach of electricity and related innovation up-degree, the power generation has touched the new heights. Yet, in the meantime, the environmental concerns made by the thermal and the nuclear reactors have turned into a migraine for the world. The words like climate change, global warming, and ozone layer depletion are known to a little kid today, which were obscure to humankind before 30-40 years. Renewable vitality era, particularly by sunlight based and wind vitality has opened another window for power generation. In this respect, the solar cell manufacturing is also becoming state-of-the-art with inventing the technology [1]-[5].

Photovoltaic (PV) power systems have made a successful transition from small standalone sites to large grid-connected systems. The utility interconnection brings a new dimension to the renewable power economy by pooling the temporal excess or shortfall in the renewable power with the connecting grid that generates base-load power using conventional fuel [6]-[9]. The solar cell manufacturing is becoming state-of-the-art with inventing the technology. Several factors have led to the evolution of the intensive use of photovoltaic systems. The PV systems installed at V.V.P. engineering college, Rajkot, Saurashtra, Gujarat, India having latitude 20.2645 and longitude 70.71322. The Saurashtra region in India is a standout amongst the best locales for the era of the sun oriented power generation. The sun is accessible for right around 10-12 hours a day for the entire year. Three essential classifications of renewable power frameworks are accessible today. (1) Stand-alone off-grid systems, which are autonomous of the grid. Aside from the immediate utilization of power in, these frameworks oblige batteries [10]-[12]. These frameworks are un-subjected to the strategies of the neighborhood utility, nor are framework proprietors subjected to the rate expand, power outages or brownouts. Maintenance, troubleshooting, smaller battery life and battery recycling environmental concerns, are some of the major issues with such systems. (2) Battery-less grid-tied frameworks. These frameworks are the least complex one. Power generation by solar photovoltaic is converted from DC to AC form with the use of an inverter and directly fed to the grid. Unavailability of backup power is one of the limitations of such systems [13]. (3) Battery-based grid-tie systems. These frameworks consolidate the upsides of the above frameworks. They have batteries as reinforcement backing and in the meantime, network to supply the surplus power or to ingest the shortfall power [14], [15]. Power is constantly accessible with such systems; however, these frameworks are exorbitant and oblige upkeep because of the vicinity of the batteries.

II. SYSTEMS AND COMPONENTS

Solar photovoltaic power generation is either done by standalone systems or by grid connected systems. Most of the systems are either one of two. V.V.P. Engineering College, Rajkot, Gujarat, India is a unique place where both these systems are in operation.

A. 60 kW Grid-Connected System

Fig. 1 shows the layout of a 60 kW grid-connected system. The system comprises of 216 number of PV modules with every module producing the maximum of 280 Watts. The modules are mounted on the rooftop having tallness 14 meters and mounting angle 13 degrees. The total active surface area is 1890 square meters. Various parameters of the system are measured using SCADA and data loggers. Every PV array consists of 4 strings connected in parallel. Every string has 18 series connected PV modules. In this way, the aggregate power generation by every module will be, 280*18 = 5040 Watts, and similarly array generates 5040*4 = 20160 Watts

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(approx. 20 kW). PV module parameters are introduced in Table I.

TABLE I
PV MODULE PARAMETERS FOR 60 KW SYSTEM

Parameter	Value
Maximum power of module (P_{max})	280 W
Maximum power point voltage (V_{mpp})	35 V
Maximum power point current (I_{mpp})	8.00 A
Short circuit current (I_{sc})	8.68 A
Open circuit voltage (V_{oc})	43 V

TABLE II
INVERTER INPUT SIDE PARAMETERS 60 KW SYSTEM

Parameter	Value
Maximum DC Power	20,450 W
Maximum input Voltage	1000 V
MPP Voltage Range	580 V- 800 V
Rated input voltage	580 V
Minimum input Voltage	570 V
Maximum Input Current	36 A
Maximum input per string	36 A

TABLE III
INVERTER OUTPUT SIDE PARAMETERS

Rated Power at 230 V,50 Hz	20,000 W
Maximum apparent Power	20,000 VA
Rated grid voltage	230V/400V
AC Voltage range	160 V - 280 V
Nominal AC current	29 A
Maximum output current	29 A
Maximum output current in case of fault	50 A

TABLE IV
INVERTER POWER GENERATION CALCULATION

Inv.	No. of modules per string	Number of strings	No. of modules × Watt	Total Watts
1	18	4	18 × 4 ×280	20160
2	18	4	18 × 4 ×280	20160
3	18	4	18 × 4 ×280	20160
Total	---------	12	54 × 4 ×280	60480

TABLE V
THE PROTECTIVE DEVICES USED

DC reverse polarity protection	Short-circuit diode
Protection against module reverse current	Diode
Input side load disconnect unit	DC switch disconnect
Utilization category of the DC switch disconnect	DC-218
DC overvoltage protection	Thermally monitored varistors
AC short circuit current capability	Current control
Grid monitoring	SMA Grid Guard 4
Maximum permissible fuse protection	50.0A
All pole sensitive residual current monitoring unit	Installed

B. Inverters

'Tripower' inverters (3 in number), 20000TL are utilized to feed this 60kVA power to the grid. Every inverter has a rated capacity of 20kVA with efficiency 98.5%. Operating temperature range of inverters is -25^{0}C to +60^{0}C with noise emission ≤ 51 dB. The degree of protection as per IEC 60259 is IP65. The output frequency is 50 Hz, and an operating frequency range is 44 Hz to 55 Hz. Inverter operating parameters are presented in Tables II and III. The inverter power generation calculation is presented in Table IV. The protective devices are listed in Table V.

C. 100kW Standalone System

The 100kW standalone PV system installed at V.V.P. engineering college, Rajkot has 440 PV modules, with each having capacity 230 Watts. Fig. 2 demonstrates the layout of the framework. Each PV string comprises of 20 series connected modules. The total plant embodies 22 parallel joined strings. Henceforth, the total power generation of standalone PV plant will be, 230*20*22 = 101200 Watts. PV module parameters are presented in Table VI.

TABLE VI
PV MODULE PARAMETERS STANDALONE SYSTEM

Parameter	Value
Maximum power of module (P_{max})	230 W
Maximum power point voltage (V_{mpp})	28.5 V
Maximum power point current (I_{mpp})	7.93 A
Short circuit current (I_{sc})	8.52 A
Open circuit voltage (V_{oc})	36.8 V
Maximum system voltage	1000 V

The entire PV system is connected directly to the Maximum Power Point Tracker (MPPT) to retrieve the maximum power at the output. The MPPT solar charger works on incremental conductance algorithm. The MPPT solar charger is connected to the voltage regulator for observing and keeping up the voltage inside recommended cutoff points. A bidirectional inverter is introduced after the voltage regulator for charging of the batteries and associating the PV framework and batteries to the AC load. The batteries are the key components in any of the standalone system. The 100kW PV system has 120 Li-ion batteries, each having capacity 1000Ah. The various parameters for standalone system inverter, MPPT based charge controller and batteries are presented in Tables VII, VIII, and IX, respectively. There are various set points for the batteries. These set points can be altered which offers adaptability to the user as per irradiation conditions, power output, and the load. Deep discharge, and additionally over the top charge securities, are acknowledged with the battery framework.

TABLE VII
100 KW STANDALONE SYSTEM INVERTER

Parameter	Value
Nominal output voltage	415V
Nominal frequency and frequency range	50 ± 3 Hz
Output supply phases	3 phase4 wire
Nominal apparent power	100 kVA
Nominal active power	100 kW
Nominal Output current	140 A

TABLE VIII
MPPT BASED CHARGER - STANDALONE SYSTEM

Parameter	Value
Input Voltage range	200-440 V
MPPT Voltage range	280-340 V
Maximum output current	370 A
Maximum output power	100 kW

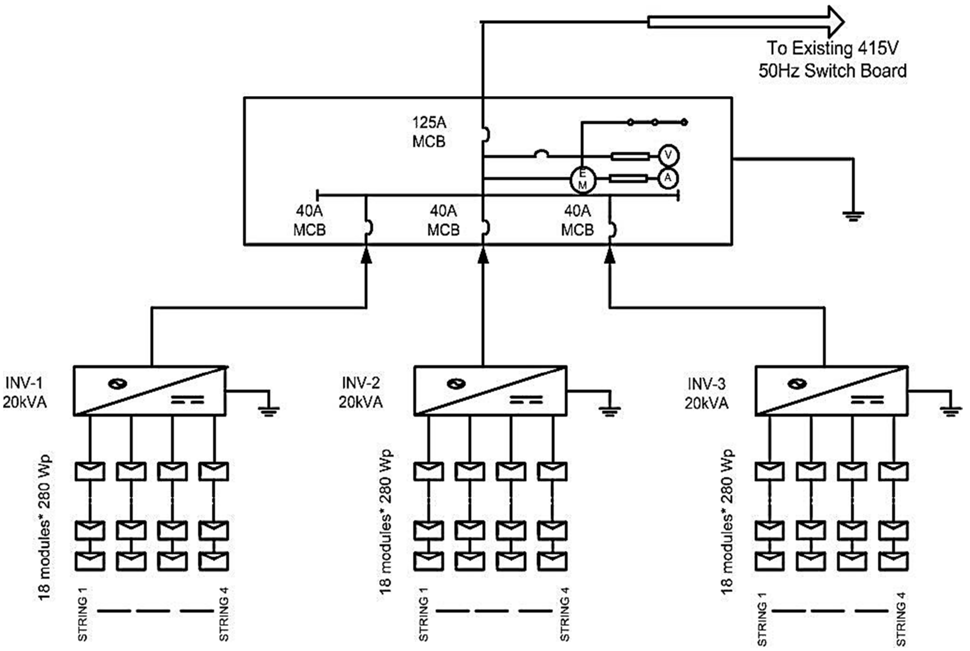

Fig. 1 60 kW Grid Connected System

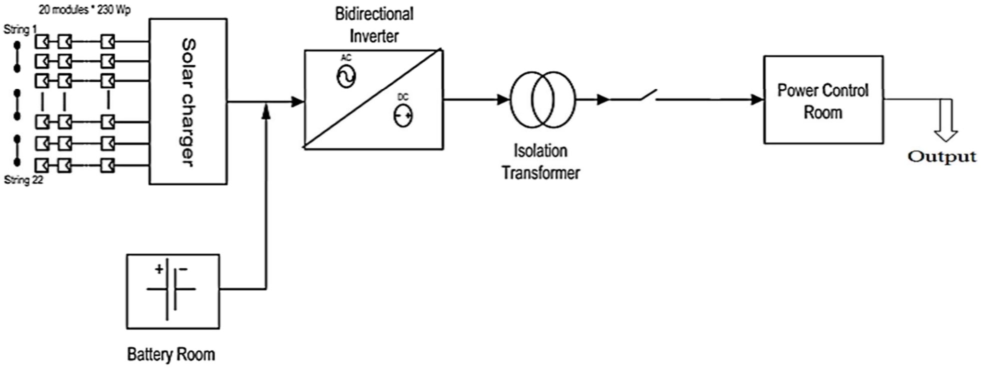

Fig. 2 100 kW Standalone System

TABLE IX
BATTERY SPECIFICATIONS

Parameter	Value
Permissible battery voltage	260 V
Battery recharge current from grid side	0-370 A
Battery recharge current from array side	370 A
Battery output power in discharge mode with nominal output load	105 kW
End battery current with nominal output load	501 A
Permissible battery voltage	260 V

III. OPERATING MODES

There are four distinct modes of operation.

A. Standalone Mode

AC voltage tracking is disabled; AC contactor is made permanently off. The inverter will pick up when the battery voltage is at 2.05V × number of the cells (120 in number).

B. Grid Charging Mode

The AC charger activates when battery voltage drops down underneath the battery grid charge start level (1.9V per cell). When the battery voltage reaches battery grid charge stop level (2.3V/cell), charging stops and the input source isolates from the inverter.

C. Grid Export Mode

In this mode, it will check battery voltage if it reaches up to battery bulk charge level (2.4V/cell) and if AC input status ok, this mode will be enabled. The export begins when the battery voltage goes above battery bulk charge level (2.4V/cell) and will stop when the battery voltage goes below battery grid charging stop level (2.1V/cell).

D. Bidirectional Mode

In this mode, grid charging, and, in addition, grid export mode will be active. By checking battery Voltage, it will decide battery charging through grid or grid export. All the variables, for example, 'grid tracking integration time' 'battery grid charge start level' and 'battery grid charge stop level' can be changed appropriately.

IV. Performance Parameters

IEC standards 61724 parameters may be used to define overall system performance. These performance parameters will be evaluated, for stand-alone and grid-connected systems. The different parameters are; solar irradiation, PV system final yield, PV reference yield, performance ration and capacity factor. On the basis of the said parameters, a comparison is made between the stand-alone and the grid-connected systems. The complete information sets will be derived from the continuous examination; the task performed by various data loggers associated with both the systems.

Solar irradiation: It is the intensity of sun rays that reaches the working surface. It is the deciding factor for PV electricity generation. Higher the intensity of sun rays, higher will be the PV electricity generation.

PV system final yield (Y_F): It is the ratio of AC energy output to the rated DC power output.

$$Y_F = \frac{E\ (kWhAC)}{Prated\ (kWDC)} \tag{1}$$

PV system reference yield (Y_R): The reference yield is the aggregate in-plane irradiance H divided by the PV's reference irradiance. It represents an equivalent number of hours at the reference irradiance. If G equals 1kW/m^2, then it is the number of peak sun-hours. It is a function of location, orientation of the PV array and month-to-month and year-to-year climate variability.

$$Y_R = \frac{Ht\ (kWh/m\hat{}2)}{1\ (kWh/m\hat{}2)} \tag{2}$$

Performance Ratio (PR): The Performance Ratio (PR) quantifies the overall effect of losses on the rated power output due to wiring mismatch, deficient utilization of irradiance by reflection, PV module temperature or the inverter efficiency. Mathematically, it is the ratio of Y_F to Y_R.

$$PR = Y_F / Y_R \tag{3}$$

Capacity Factor (CF): The capacity factor represents the energy delivered by an electrical power generating system. The capacity factor will be equal to 1 if the system delivers full rated power continuously. It is the ratio of actual annual energy output to the amount of the energy PV system would generate if it is operated at full rated power for 24 hours a day, for the entire year.

V. Analysis and Comparison of Standalone and Grid-Connected System

The sun oriented illumination over diverse months and days at the V.V.P. Engineering College, Rajkot, Saurashtra, Gujarat, India having scope 22.2645 and longitude 70.71322 was measured and logged using the information logger. The variations in the solar radiation, total monthly output yield, final yield, average monthly output, total monthly energy generated by the system, performance ratios, capacity factors, state of the charge of the batteries of stand-alone system, inconsistencies in the voltage, power and the load current were measured or computed. The associated graphs were plotted with the accessible information, demonstrating the contrast in both the systems. The frameworks were operated, from October 2014 until March 2015. The season of these six months is the ideal for power generation by the sun situated photovoltaic in the Rajkot region when the sun-based light, and consequently, the yield of the structures, is at its crest.

A. Total Yield Measurement

Day by day yield was utilized to calculate the month after month yield. This is indicated in Table X. Fig. 3 shows the graphical representation of Total in-plane radiance (kWh/m^2) for the said period of six months. Fig. 4 compares off-grid and on-grid systems relying on their final yields.

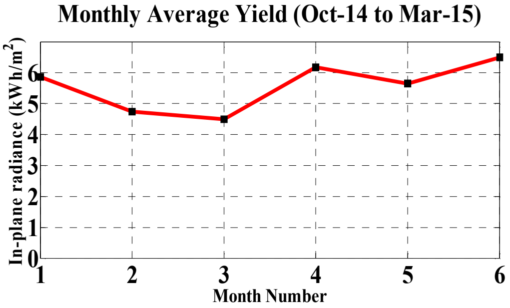

Fig. 3 Total in-plane irradiance (Oct-2014 to Mar-2015)

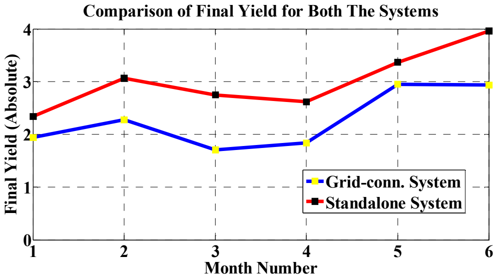

Fig. 4 Final yield comparison for both the systems

TABLE X
Monthly Average Yield (Oct-2014 to Mar-2015)

Month	Total in-plane radiance (kWh/m^2)	Final Yield	
		Grid-connected system	Standalone system
Oct-14	5.86	1.94	2.34
Nov-14	4.74	2.28	3.07
Dec-14	4.49	1.71	2.75
Jan-15	6.17	1.84	2.62
Feb-15	5.65	2.95	3.37
Mar-15	6.50	2.94	3.96

B. Total Energy Consumed since October 2014 to March 2015

The V.V.P. engineering college has an aggregate connected load of approximately 350 kW, and the average load is 180 kW. The energy consumption data, as well as PV generation data by the stand-alone and the grid-connected systems obtained from the loggers, were plotted on the everyday base for the six months. Figs. 5-10 show the daily, and hence, monthly energy consumption and energy generation by the two said systems within the premises in a graphical manner. The figures conclude that minimum energy consumption is in the month of October due to winter, and the maximum in the month of March in light of the summer season. The energy consumption is also affected by Saturdays, Sundays and public holidays. The plots also show that the energy generation by the stand-alone system is greater than the grid-connected system due to higher capacity and better performance ratio. The capacity factor and the performance ratio calculation are also shown in the upcoming paragraphs and they are better for the stand-alone system.

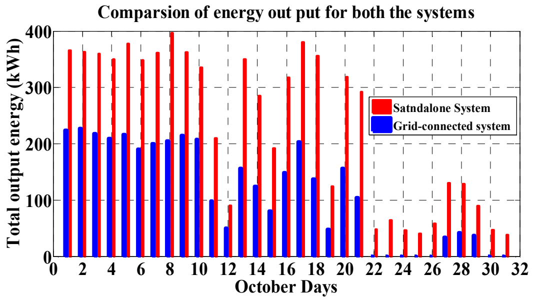
Comparsion of energy out put for both the systems

Fig. 5 Total output energy October -2014 (Day by Day)

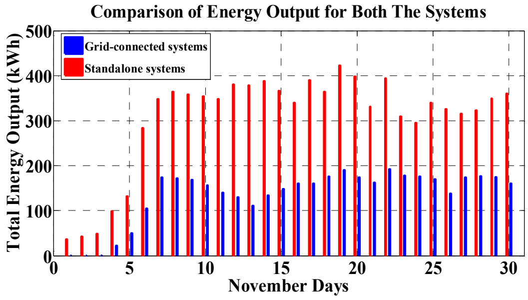
Comparison of Energy Output for Both The Systems

Fig. 6 Total output energy November -2014 (Day by Day)

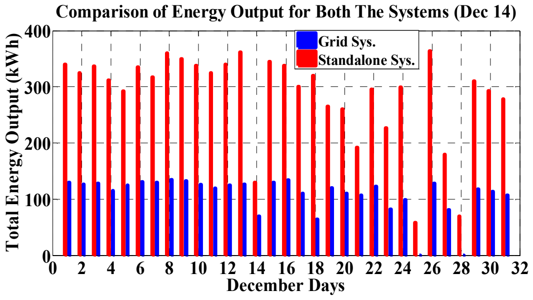
Comparison of Energy Output for Both The Systems (Dec 14)

Fig. 7 Total output energy December -2014 (Day by Day)

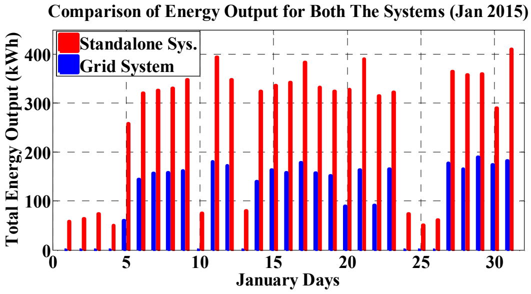
Comparison of Energy Output for Both The Systems (Jan 2015)

Fig. 8 Total output energy January- 2015 (Day by Day)

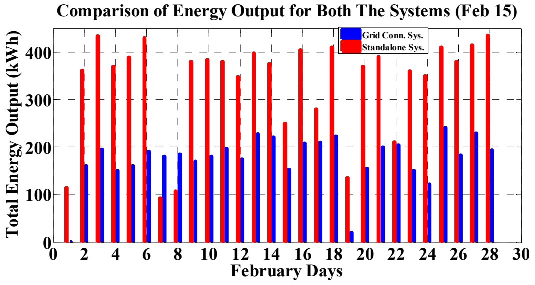
Comparison of Energy Output for Both The Systems (Feb 15)

Fig. 9 Total output energy February- 2015 (Day by Day)

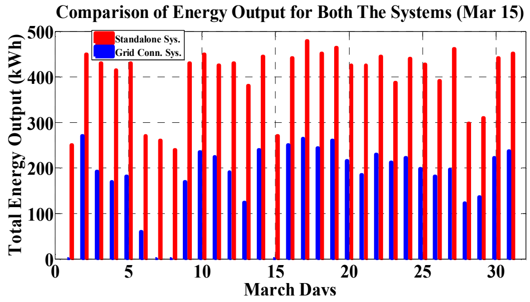
Comparison of Energy Output for Both The Systems (Mar 15)

Fig. 10 Total output energy March- 2015 (Day by Day)

TABLE XI
PERFORMANCE RATIO AND CAPACITY FACTOR FOR BOTH THE SYSTEMS

Month	Performance Ratio		Capacity Factor	
	Grid-conn.	**Stand-alone**	**Grid-conn.**	**Stand-alone**
Oct-14	0.32	0.39	0.1550	0.1655
Nov-14	0.48	0.65	0.1875	0.1921
Dec-14	0.38	0.61	0.1775	0.1871
Jan-15	0.35	0.51	0.1625	0.1721
Feb-15	0.52	0.59	0.1345	0.1398
Mar-15	0.45	0.61	0.1455	0.1542

C. Comparison of Performance Ratio and Capacity Factor

The analysis is carried out by calculating the performance ratio and the capacity factor for both the systems. The performance ratio is already defined, as the ratio of the PV system final yield (YF) to the PV system reference yield (YR). The capacity factor is calculated as referenced in Section IV. These ratios and their comparison for both the systems are shown in Table XI. The comparison of performance ratios shows that it is higher for the stand-alone system with reference to the grid connected system, proves the ability to give the higher output of the stand-alone system. The capacity factors for both the systems are practically identical but still the stand-alone system is a winner by a small margin in this regards.

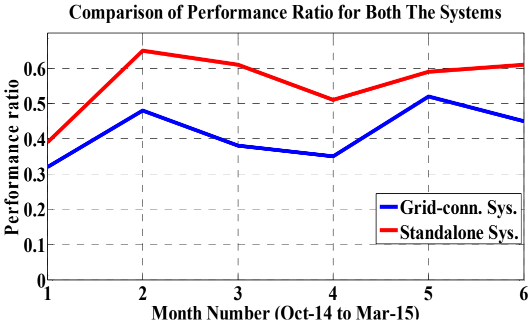

Fig. 11 Comparison of the Performance Ratio for both the systems

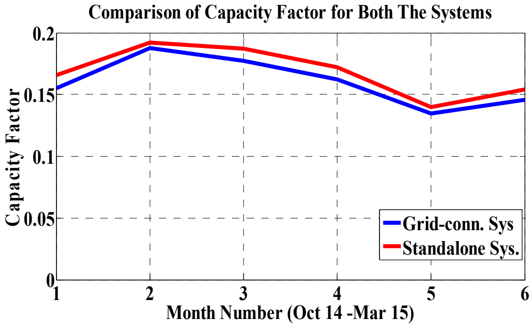

Fig. 12 Comparison of the Capacity Factor for both the systems

D. Comparison of Voltage and Power Fluctuations

Tables XII and XIII show the voltage variation for the stand-alone and grid-connected systems. The data of Tables XII and XIII make it clear that the grid connected system has better control over the voltage and normally it has positive voltage regulation. This voltage regulation is normally negative for the stand-alone system as shown in the data of Table XII. Figs. 13-16 are drawn on the basis of these tabular readings. The better voltage regulation in the grid-connected system is due the fact that on inverter side, it has reactive power support from the grid and therefore it can deal with these kinds of variations in a better way. The standalone system due to the absence of this support has higher voltage fluctuations. Moreover, the grid connected system, as shown in Fig. 17 has lesser power variations with reference to the standalone system. This again proves the support given by the grid and hence larger system inertia and hence fewer fluctuations in power magnitude.

TABLE XII
VOLTAGE VARIATION IN % FOR THE STAND-ALONE PV SYSTEM

Time (Minutes)	Voltage (Stand-alone)	Ref. Voltage (Stand-alone)	% Difference
0	269.55	275	-1.98
30	269.11	275	-2.14
60	272.65	275	-0.85
90	276.32	275	-0.48
120	264.86	275	-3.68
150	256.21	275	-6.83
180	281.57	275	2.38
210	266.26	275	-3.17
240	264.81	275	-3.70
270	276.92	275	0.70
300	257.34	275	-6.42
330	271.98	275	-1.10
360	267.69	275	-2.66

TABLE XIII
VOLTAGE VARIATION IN % FOR THE STAND-ALONE PV SYSTEM

Time (Minutes)	Voltage (Grid-connected)	Ref. Voltage (Grid-connected)	% Difference
0	599.63	600	-0.0616
30	603.65	600	0.6083
60	616.59	600	2.7652
90	613.45	600	2.2416
120	614.51	600	2.4183
150	611.17	600	1.8616
180	619.67	600	3.2783
210	619.75	600	3.2916
240	612.68	600	2.0881
270	612.45	600	2.0753
300	608.45	600	1.4081
330	614.63	600	2.4305
360	609.41	600	1.5682

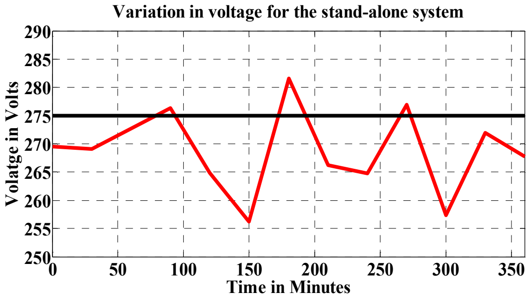

Fig. 13 Voltage variation with time in the stand-alone system

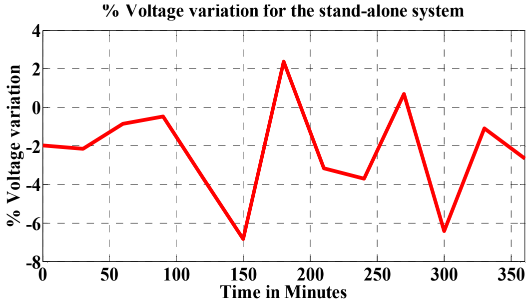

Fig. 14 % Voltage variation with time in the stand-alone system

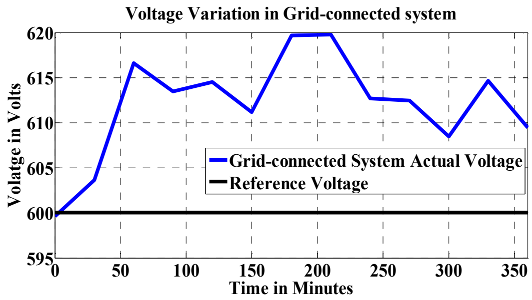

Fig. 15 Voltage variation with time in the grid-connected system

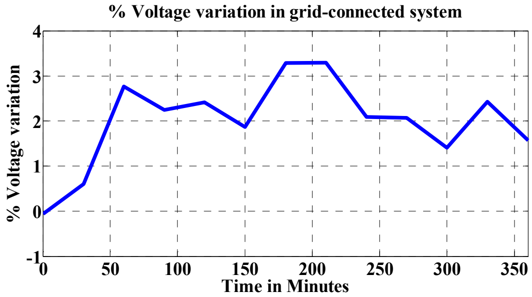

Fig. 16 % Voltage variation with time in the grid-connected system

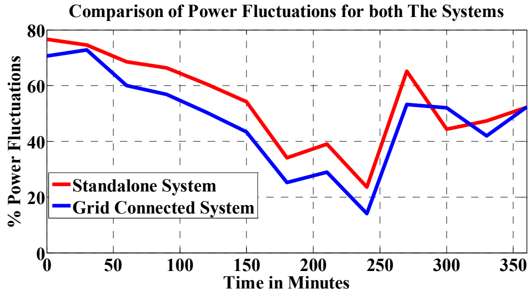

Fig. 17 Comparison of Power fluctuations for both the systems

The analysis for the voltage and power fluctuations was carried out for a winter day (Month of December at Rajkot) for 6 continuous hours (360 Minutes) and other days also have given the identical results. It is also a matter of Fact that normally stand-alone systems have inductors or reactors at the output side to smooth out the transients, but it will be responsible for the extra voltage drop and hence the actual system voltage is normally lesser than the reference voltage, which makes voltage regulation negative. In the analyzed system, this voltage drop is around 5 volts in the normal operating conditions.

E. Comparison of the Monthly Energy Generated

The comparison of both the systems on the basis of Yield in kWh, total monthly energy generated during the defined period of six months and comparison of load current is also made in Figs. 18, 19, and 20, respectively. Figs. 18 and 19 show that due to higher capacity, better performance ration and better capacity factor, the monthly total energy generated by a stand-alone system is higher than the grid-connected system.

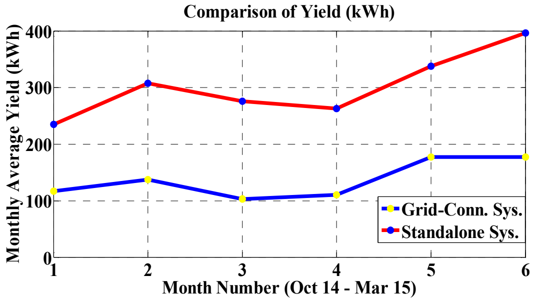

Fig. 18 Comparison of Yield (kWh) for both the systems for six months

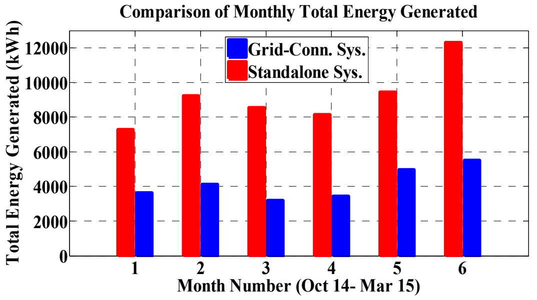

Fig. 19 Comparison of monthly energy generated for both the systems for six months

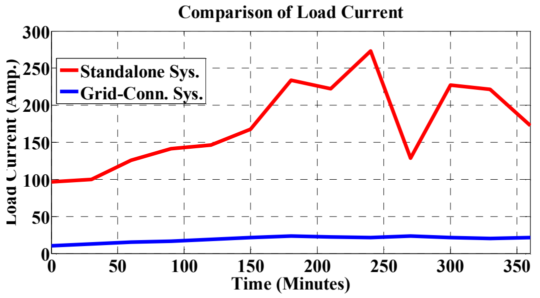

Fig. 20 Comparison of load current fluctuations for both the systems

F. State of the Charge (SOC) of the Batteries

The SOC of the battery is an important indication of health and condition of the battery. The batteries used in the standalone PV system; at V.V.P. Engineering College has total string voltage of 260 V, and can work for 2 days in autonomy. The SOC for the batteries is calculated by using the standard tables for Li-Ion batteries [16]. The voltage-SOC data is indicated in Table XIV. The variations over 3 hours are shown in Fig. 21. The battery SOC is registered within the permissible operating range. The data shown for 3 hours of operation of the batteries and it is generally true for throughout the year as the system had given the nearly identical results for all such days.

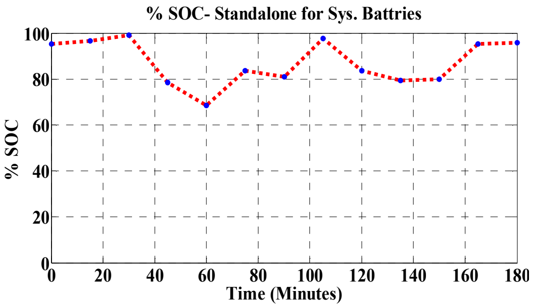

Fig. 21 SOC of the battery set for stand-alone system

TABLE XIV
SOC OF THE BATTERIES

Time (Minutes)	**Voltage (Stand-alone)**	**% SOC**
0	253	95.12
15	255	96.62
30	259	99.16
45	246	78.43
60	244	68.52
75	251	83.65
90	249	81.02
105	258	97.72
120	251	83.65
135	248	79.32
150	247	79.93
165	253	95.12
180	254	95.91

VI. CONCLUSION

The paper demonstrates the continuous exploratory examination between the stand-alone and the grid-connected PV frameworks. The real-time parameters like output voltage, load current, power in-flow, power output, performance ratio, yield factor and capacity factor etc. are compared for both the systems situated at V.V.P. engineering college, Rajkot. The voltage changes and the power variances in both the systems are given special attention. The comparison shows that the stand-alone system has better performance ratio and capacity factor, whereas, the grid connected system is superior when power fluctuations and voltage variations are considered. The SOC of the batteries and their life cycle is a big challenge in stand-alone PV system and on the other hand reliability of the system is enhanced to a great deal. In this way, it relies upon the system designer to go for the specific system but the grid connected system with battery backup can lead to the best possible solution where the power fluctuations and voltage variations can be minimized and at the same time performance ratio and capacity factor will have improved values.

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