Efficiency Analysis of a Solar Photovoltaic DC and Existing AC Distribution System for Bahirdar University Data Center

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Abstract. Data centers are multipurpose internet based centers which needs to perform different tasks without any perturbation of electric power. It is a very fast growing structures with significant contribution to the world's energy consumption. For this paper, Bahirdar University data center is selected for reliability and efficiency evaluation of both AC and DC distribution system architecture. The study is based on the existing AC power distribution layout of the selected case area which gets supply from Ethiopian electric utility (EEU) with a nearby diesel generator as a backup power supply system in a case of power outage from the utility system as well as the proposed data center power distribution model with an off grid solar powered 380 V DC distribution system. Results show that an AC distribution system has an average efficiency of 72.96% while a proposed DC distribution system has an average efficiency of 82.63%. This demonstrated that a DC power distribution system is 9.67% efficient than AC power distribution architecture. The simulation analysis was done in MATLAB.

Keywords: Data center · DC distribution · Efficiency analysis

1 Introduction

Recently, DC distribution system has many advantages over an AC distribution system. An improved power quality, higher efficiency and reliability are some of the merits listed in DC distribution systems. It has also reduced installation costs as it requires fewer power conversion stages, less copper, no reactive power or skin effect and smaller floor space. Integration of renewable energy sources and energy storage systems are simple in DC distribution since it does not require any synchronization. Telecommunication systems and data centers are among the few surviving examples of DC distribution systems [1]. Data centers are very fast growing structures with significant contribution to the world's energy consumption. The main source of electricity for a data center is usually the grid connection which is provided by utility companies, although there are some exceptions like Apple's data centers which claim to use 100% renewable energy [2].

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Now a day, the renewable energy sources such as solar PV, wind, geothermal, biomass energy and other sources of energy leads to replace the dependency of electricity from utility system. Power convertors like rectifiers, inverters and choppers are also more applicable to change the voltage type and level from one state to another. These convertors are now more applicable for DC distribution systems [2].

A data center is a multipurpose internet based center which needs to perform different tasks without any perturbation of electric power that comprises critical and sensitive load comprises of IT equipment's such as servers, switches storage devices and UPS systems that are typically DC-based loads. Thus, this study leads to push on the design of DC distribution for data center power distribution architecture to improve the efficiency and reliability of the system For this paper, Bahir Dar University data center is selected for reliability and efficiency evaluation of AC and DC distribution system by properly designing an off grid solar power with a backup diesel generator to supply the data center loads to replace utility power supply.

Bahir Dar University gets electric power supply from Ethiopian electric power industry at a nearby substation through 15 kV distribution line. Bahir Dar University data center is one of the large loads of the university which is very sensitive to the power interruption in the utility side. In most cases the power is interrupted due to different faults at the feeder lines of the substation which feeds the university loads leads to fail the data center power supply. System failure is the problem of data center power reliability. High reliability requirement of a data center can be achieved by appropriate design of the data center electric power distribution architecture.

The availability of power is increased by using multiple main supplies, alternative energy sources such as solar and wind, and standby diesel generators [3].The many cascaded power conversion stages and the low efficiency of each converter are the causes of low data center efficiency. All power conversion stages in the power distribution system should be high-efficiency in order to achieve high overall efficiency. Hence, implementation of a DC distribution system instead of AC distribution system results in elimination of a number of conversion stages, thereby reducing the distribution losses resulting in efficient distribution system [3].

2 Data Center Topologies and Components

One of the major concerns of data centers is to ensure continuous energy supply to its load and to improve the energy efficiency [7]. As servers in data center runs applications for flow of information and data to and from different parts of the world, continuous supply of power to the server load and supporting infrastructure (cooling and lighting loads) is needed at all times. Nowadays, there are different topologies used in data center's power distribution system. An appropriate power supply option has been chosen based on the reliability and availability of the power distribution topologies and type and size of a data center.

Tier Classifications: Uptime Institute standardized the Tier classification system for data centers as a means to evaluate data center infrastructure in terms of their availability. The Uptime Institute has defined four Tier system topologies for describing the availability as shown in Fig. 1 [7]. These are Tier I, Tier II Tier III and Tier IV. Each tier has a specific function and its appropriate criteria for power, cooling, maintenance, and capability to withstand a fault. Tiers are progressive, meaning each Tier incorporates the requirements of all the lower Tiers.

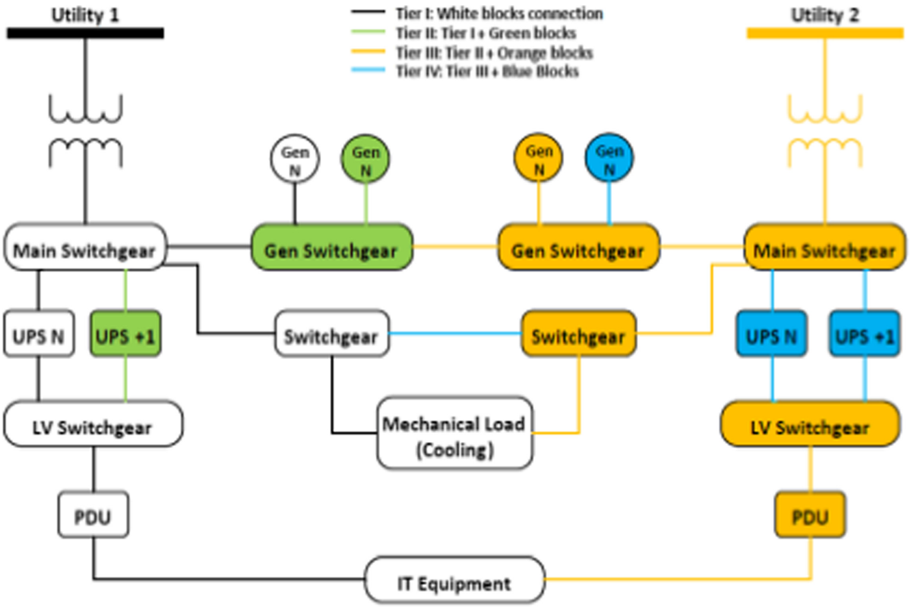


Fig. 1. Topologies for different tier systems [8]

The comparison of different Tier systems is shown in Table 1.

Table 1. Comparison of Tier systems [8]

	Tier I	Tier II	Tier III	Tier IV
Distribution paths	Only one	Only one	1 active and 1 Alternative	2 simultaneously active
Concurrently maintainable	No	No	Yes	Yes
Fault tolerance	No	No	No	Yes
Annual IT downtime	28.8 h	22 h	1.6 h	0.4 h
Site Availability	99.67%	99.75%	99.98%	99.99%

The data center in case of this study is a Tier II standard which has one active supply system with two sources, one from utility and the other is a diesel generator as a backup source. Throughout this study Tier standard listed in Table 1 has been used.

Components of a Typical Data Center: The components of any data center can be broadly categorized into energy source, power distribution path and data center load. These components are described in the next section.

3 Resource Assessment and System Parameter Metrics

The load profile and solar radiation data has been collected. To supply all data center loads using solar energy, all procedures and mathematical equations of solar design/sizing are considered. The electrical power distribution architecture of existing (AC) system and a proposed solar powered DC distribution would be explained. The preference of DC distribution over an AC distribution and the standard selection of DC voltage for distribution system have been described. Finally, the proposed distribution system could be compared with an existing AC power distribution system in terms of efficiency and reliability.

3.1 Data Center Load Profile

As explained above a data center consist both IT load and supporting infrastructures. IT load comprises of server load, switches, and routers and so on. It is a critical or sensitive load of a data center. Other loads such as computer room air-conditioners (CRACs), lighting, and switchgears are known as supporting infrastructure for IT load. Table 2 below shows the load profile data for selected study case area.

Table 2. Data center load profile

Load	Watts	H/day	Number	Watt – Hr
Air Conditioner	3200	24	2	7600
IT load	120	24	70	201600
Un interruptible Power Supply (UPS)	16000	0.0916	2	2931.2
Lighting	18	12	10	2160
Computer (Desktop)	120	8	4	3840
Security System	120	24	1	2880
—	—	—	—	—
Total daily watt and Watt-Hr/day	**45,910 W**			**220,931.2 Wh/day**

Based on Table 2, data center consists of 12 racks for the IT critical loads and each rack contains 10 servers with peak power usage of 120 W on the data nameplate. From the table above, estimated energy capacity at full load, is 220.931.2 Wh/day or 289.4112 KWh/day.

3.2 Solar Resource Assessment of Selected Site

Bahir Dar area gets enough sun for standalone as well as grid-connected photovoltaic systems to operate well. The site location from NASA is shown in Fig. 2. The data center is installed in one sectional room of a large building in the university compound and it is free from shading and also gets sun in all times of a day.

Table 3. Monthly averaged radiation (kWh/m^2/day)

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
KWh/m^2/ day	6.4	6.7	7.0	6.9	6.6	5.6	4.6	4.8	6.03	6.6	6.4

Fig. 2. Solar resource potential and site map of the case study area

The data center is located at the 11.5742°N latitude and 37.3614°E longitude and has the following Monthly Averaged Radiation (kWh/m^2/day) is indicated in Fig. 2. From the above table, the maximum average radiation is 6.14 kWh/m^2/day in January and minimum radiation is 4.6 kWh/m^2/day at August.

3.3 System Parameter Metrics and Estimation Methods

The system efficiency and reliability analysis is based on the power distribution components. Their power distribution system (AC or DC) determines both efficiency and reliability of data center. This will further discussed by the next sections.

Data Center Efficiency: The efficiency of a system is expressed as the fraction of its input that is converted to the desired useful output. For data centers, the input is electricity and the useful output is power for the IT load.

$$\text{Data center efficiency} = \frac{\text{IT load power}}{\text{Total data center power}} \tag{1}$$

Data Center Efficiency Metrics: The large portion of energy consumption by data centers is causing a significant impact on the electrical grid and the environment. Hence, there should be metrics to measure data center's effectiveness. Metrics are used to measure and improve the effectiveness of some value, function or parameter. Power Usage Effectiveness (PUE), Water Usage Effectiveness (WUE), Energy Reuse Effectiveness (ERE), Data Center Compute Efficiency (DCCE), and Clean Energy Index are most widely used metrics nowadays to measure data center effectiveness. PUE is the most common metric used in data centers [13].

Power Usage Effectiveness (PUE): When compared to electricity utilized by cooling, lighting, and other extra plant within the data center, PUE reflects how much of this power is actually used by the IT equipment [13]. The ideal value of PUE is 1 and a lower PUE value indicates a more efficient data center. PUE is calculated by:

$$\text{PUE} = \frac{\text{P}_{\text{total}}}{\text{P}_{\text{ITload}}} \tag{2}$$

where, $\text{P}_{\text{total,}}$ is the total power consumed by the data center and.

$\text{P}_{\text{IT load,}}$is the power consumed by the IT load.

Data Center Infrastructure Efficiency (DCiE): Data Center Infrastructure Efficiency (DCiE), the inverse of PUE, is a metric used to determine the energy efficiency of a data center. The ideal value of DCiE is 1.[13] DCiE is also expressed as a percentage, is calculated by dividing IT equipment power by total facility power.

$$\text{DCiE} = \frac{1}{\text{PUE}} = \frac{\text{P}_{\text{ITload}}}{\text{P}_{\text{total}}} \tag{3}$$

Data Center Compute Efficiency (DCcE): Server in data centers are designated to perform specific task known as primary services. For example, primary service of an email server is to provide email services when requested [13]. Depending upon the primary service provided by the server, the server compute efficiency can be calculated by:

$$\text{SCE} = \frac{\sum_{i=1}^{n} \text{Pi}}{\text{m}} \times 100 \tag{4}$$

where Pi is the number of primary service provided by the server, n is total number of sample taken over time. Also, for given data center having m servers, DCcEis calculated by averaging the *ScE* values from all servers during the same time period calculated by:

$$\mathrm{DCcE} = \frac{\sum_{j=1}^{n} \mathrm{SCEj}}{\mathrm{m}} \times 100 \tag{5}$$

4 Sizing and Models of Proposed DC-System Components

4.1 Sizing System Components

The first step is to estimate daily electrical demand. Thus, according to Table 2 the daily estimated energy capacity at full load is 220,931.2 Wh/day or 289.4112 KWh/day. For this design, August is the design month that is 4.6 $\mathrm{KWh/m^2/day}$ given in Table 3 for 25 years life span. A typical module is selected for design purpose and its specification also shown in Table 4. The performance of PV modules and arrays is generally rated according to the maximum DC power output and current. 300 Wp-*JSSP-24300, e*asily available Module in Ethiopian market, is selected as shown in Table 4 with important specifications.

Table 4. Specification of typical PV- module for design purpose (JSSP-24300) [24]

Specification	Value
Maximum power current (I_{mp})	8.3 A
Maximum power voltage (V_{mp})	36 V
Max. Power (P_{max})	300 W
Short circuit current (I_{sc})	8.9 A
Open circuit voltage (V_{oc})	44 V

The following constants are also taking into consideration for the general design of PV system [15].

- Battery efficiency (%) = (0.8 < × < 0.85) for round trip average efficiency of a new battery. Typical percentages of the losses in a PV system are temperature losses = 0.9 and wiring losses = 0.97
- Combined efficiency = 0.85 * 0.9 * 0.97 = 0.74, Inverter efficiency = 0.9 and Output efficiency, $\eta_{out} = 0.85 * 0.9 = 0.765$
- Depth of discharge, DOD = 0.65

For the most efficient and reliable power distribution in modern data centers with standalone PV system case, 380 V is selected as off grid supply of data center loads since 380 V has relatively better performance compared to 120 V, 48 V, 24 V and 12 V DC distribution systems. The procedures summarized in Table 5 are step by step methods for which to design/size PV array, Charge controller, Battery capacity and other necessities to supply the proposed system from standalone solar power system [15].

Table 5. Procedures for sizing the PV system

Step	Expression	Description
PV- array sizing [11]	$P_{pv} = \frac{E_{pv}}{G_{min}} \times 1000\ w/m^2$	P_{pv} is the total power of PV array in watts E_{pv} is the total energy required from PV array and G_{min} is the minimum solar radiation of a month
$PV\ array\ (w) = fill\ factor \times PV\ array\ (w)$		By considering fill factor (FF) as 0.77
Battery sizing [11]	$E_{bat} = \frac{E_t \times \text{days of autonomy}}{DOD \times \eta_{out}}$ Wh/day	E_{bat} is battery energy storage capacity DOD is maximum permissible depth of discharge η_{out} is the output efficiency of the battery
Number of batteries required		$N = \frac{C_{bat}}{rating}$
Sizing of charge controller [11]	$I_{controller} = N_{parallel} \times I_{sc} \times 1.3$	I_{sc} - represents the size of solar charge controller $N_{parallel}$ is the number of parallel solar modules
Inverter sizing [11]	$P_{inv} = P_{acload} \times CF$	P_{inv} - the rating of inverter in watt CF - the correction factor for safety $P_{ac\ load}$ represents the total ac electrical load in watt

Accordingly, summary of sizing results are presented in Table 6.

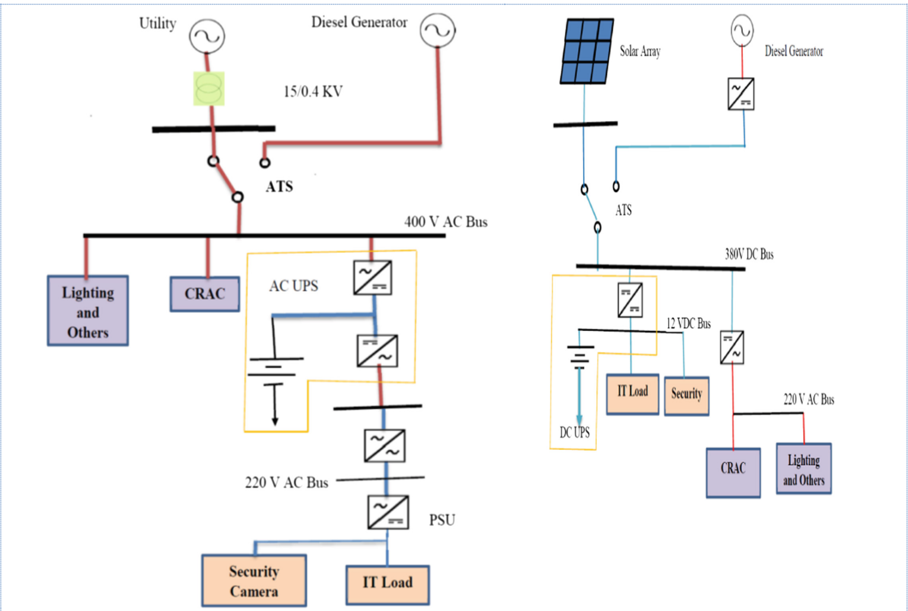
Table 6. A summary for PV system component sizing

Component	Description of component	Result
Load	Total estimated load (kW)	45.9
	Total estimated energy (kWh)	220.93
PV Array	Capacity of PV array (kW)	52.8
Number of modules in series		16
Number of modules in parallels		11
Total number of modules		176
Battery Bank	Battery bank capacity (Ah)	1334.8
Number of batteries in series		16
Number of batteries in parallel		4
Total number of batteries required		72
Inverter	Capacity of the inverter (kW)	9

4.2 System Component Models

Existing (AC) Power Distribution System of a Data Center: Figure 3(a) shows the single line diagram of existing AC power distribution system for Bahirdar University Data Center which has one main source from the utility system (EEU) and a diesel generator as aback up source. One distribution transformer is used in this model. The distribution transformer steps down the 15 kV AC bus voltage to distribution level voltage, 400 V before connecting to the 400 V AC bus of the data center input.

The Proposed 380 V DC Power Distribution System Model: The proposed system contains a designed solar array as a main source of supply and one diesel generator as a backup source. The renewable energy source (in this case solar array) is used to replace the utility source in order to independently supply the data center loads to eliminate power interruptions from the utility system. The data center has a load of 45.9 KW power with DC power distribution architecture with a backup diesel generator and is designed to have 196 solar panels each having 300 W power ratings with 16 strings to be connected to the 380 V DC bus to achieve the required load capacity as shown in Fig. 3(b). It consists of three converters which lead to have relatively good efficiency as compared to AC distribution with five converters.



(a) Single line diagram of existing data center AC

(b) Single line diagram of proposed 380V DC

Fig. 3. Single line diagram representations for the existing AC and the proposed DC system

4.3 Main Components Loss and Efficiency Modeling

The data center's efficiency can be determined empirically by summing up the power consumption of all IT equipment and dividing by the total power input of the data center. This method is simple, but gives an overstated efficiency result of data centers. Another approach is to use manufacturer provided efficiency for the data center main components such as UPSs, inverters, rectifiers and PSUs. Manufacturers provide efficiency data for the data center components which underestimate the losses [17].

Components Loss Model:

The accuracy of data center efficiency estimation is determined by the validity of each data center component's efficiency models.As illustrated in Eq. 6, a component's losses can be evaluated as the total of three losses: no-load loss, proportional loss, and square-law loss [17].

$$\text{Component}^{'}\text{s loss} = \text{No} - \text{load loss} + \text{Proportional loss} + \text{Square} - \text{law loss} \tag{6}$$

Now, the component loss can be computed by using Eq. 7.

$$\mathrm{P_{loss}} = \mathrm{K_0} + \mathrm{K_1 L_{\%}} + \mathrm{K_2 L_{\%}^2} \tag{7}$$

where L % is the component load as a percentage of its rated active power, and K0, K1 and K2 are the no-load, proportional loss, and square-law term coefficients, respectively, that are determined through regression analysis of the loss data provided by the manufacturer at multiple load levels, which are 0% (no-load), 25%, 50%, and 75%. (full load). The component losses are computed by subtracting the output power from the input power using Eq. 8.

$$\mathrm{P_{loss}} = \mathrm{P_{in}} - \mathrm{P_{out}} \tag{8}$$

The component loss can also be expressed as the percentage of its rated power and the results in Eq. 9.

$$\mathrm{P_l} = \mathrm{K_{p0}} + \mathrm{K_{p1} L_{\%}} + \mathrm{K_{p2} L_{\%}^2} \tag{9}$$

where,

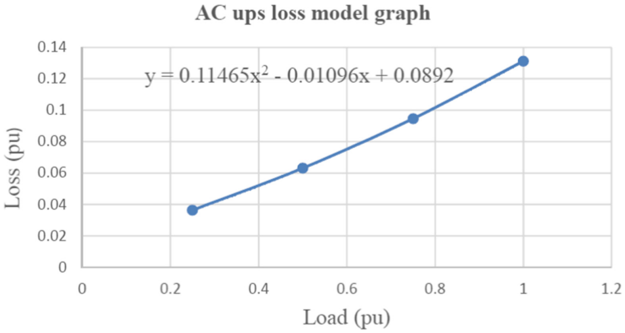
$$\mathrm{P_l} = \frac{\mathrm{P_{loss}}}{\mathrm{P_{rated}}} \quad \text{And} \quad \mathrm{K_{pz}} = \frac{\mathrm{K_z}}{\mathrm{P_{rated}}}; \quad z = 0,\ 1,\ 2$$

As the values of the per-unit component losses $\mathrm{P_l}$ and the component's per unit load $L_{\%}$ are known, regression analysis is used to determine the values of the loss term coefficients: K_{p0}, K_{p1} and K_{p2}.

From Eq. 9, as the values of the per-unit component losses P_l and the component's per unit load $L_{\%}$ are known, regression analysis is used to determine the values of the loss term coefficients: K_{p0}, K_{p1} and K_{p2}.The following tables describe the mathematical model of loss and efficiency of main data center components which is provided by this

Load (p.u.)	0.25	0.50	0.75	1.0
Loss (p.u.)	0.0364	0.0631	0.0946	0.1312

(a) Measured AC UPS loss data (p.u.) at multiple load levels (p.u) [19]



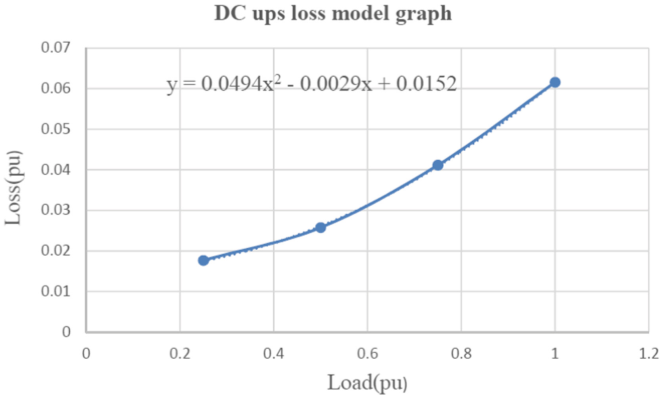
(b) Interpolated model of AC UPS losses

Fig. 4. Measured AC UPS and interpolated model

study. The UPS loss data is considered here for both AC and DC type UPS. Loss data of typical double conversion AC UPS was extracted from [18]. The loss data expressed in per unit value at different loadings are shown in Fig. 4(a). A regression analysis (or

Load (p.u.)	0.25	0.50	0.75	1.0
Loss (p.u.)	0.01767	0.02576	0.04114	0.06157

(a) Measured 380V DC UPS loss data (p.u.) at multiple load levels (p.u.)

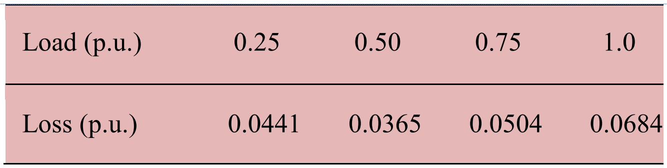


(b) Interpolated model of DC UPS losses

Fig. 5. Measured 380 V DC UPS and interpolated loss model

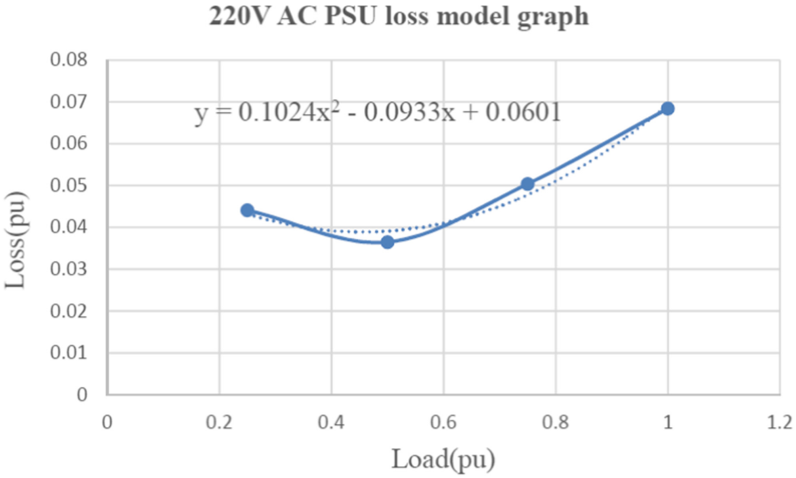
second order polynomial fit) was done for this loss data and plotted in Fig. 4(b). It can be seen from the figure that the values of K_{p0}, K_{p1} and K_{p2} for AC UPS loss model are respectively 0.0892, −0.01096 and 0.11465.

Similarly, loss data of a DC UPS was extracted from efficiency data in [18]. The loss data expressed as percentage of the rated load at different loadings are shown in Fig. 5(a). A regression analysis (or second order polynomial fit) was again done for this loss data and plotted in Fig. 6. From Fig. 5(b), it can be seen that the values of K_{p0}, K_{p1} and K_{p2} for DC UPS loss model are respectively 0.0152, 0.029 and 0.0494.



Load (p.u.)	0.25	0.50	0.75	1.0
Loss (p.u.)	0.0441	0.0365	0.0504	0.0684

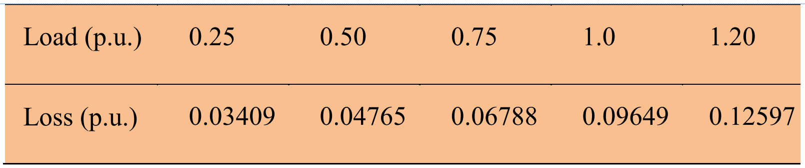
(a) Measured 240V AC PSU loss (p.u.) at multiple load levels[19]



(b) Interpolated model of AC PSU losses

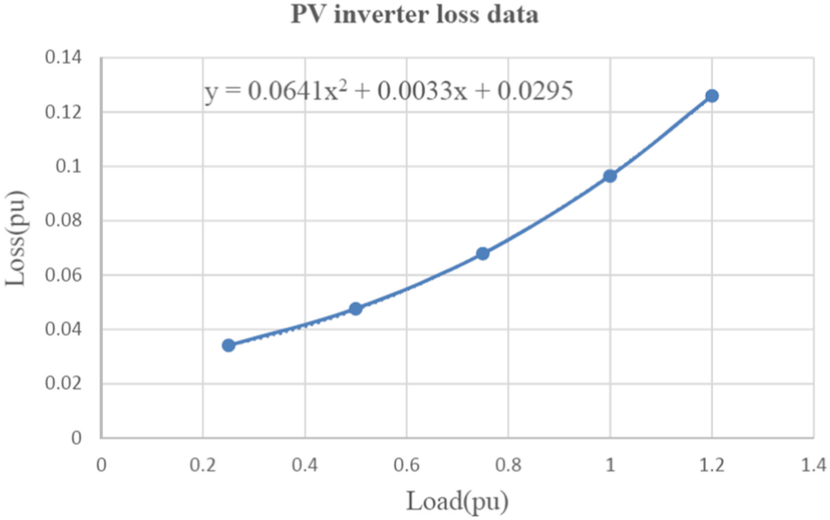
Fig. 6. Measured AC PSU and interpolated loss model

Power supply unit: The loss data and their second order polynomial fit of AC power supply unit in the model used in this paper is given in Fig. 6. For AC power supply unit, a measured 240 V loss data was extracted from [18] which is approximated with 220 V supply unit and its polynomial fit is constructed as shown in Fig. 6(a). The interpolated second order polynomial fit of this AC PSU loss is plotted in the following graph.



Load (p.u.)	0.25	0.50	0.75	1.0	1.20
Loss (p.u.)	0.03409	0.04765	0.06788	0.09649	0.12597

(a) Measured PV inverter loss data (p.u.) at multiple load levels (p.u.)



(b) Interpolated model of PV invertor losses

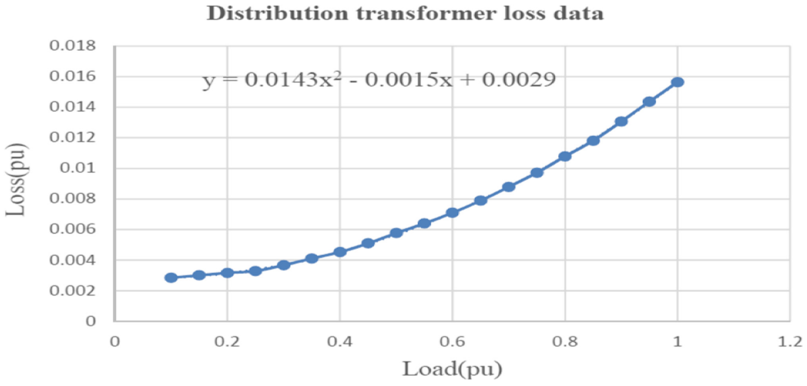
Fig. 7. Measured PV inverter and interpolated loss model

The loss data taken for the inverter is a loss data from a 240 V type inverter which is extracted in [19] approximated with 220 V inverter to determine the component loss coefficients. Based on this data, a regression analysis graph was done as shown in Fig. 7(b).

The loss data of distribution transformer was obtained from [20] and it is shown in Fig. 8(a). A regression analysis (or second order polynomial fit) was again done for this loss data and plotted in Fig. 8(b).

Load	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	0
Loss	0.002	0.003	0.003	0.004	0.005	0.007	0.008	0.010	0.013	0.015

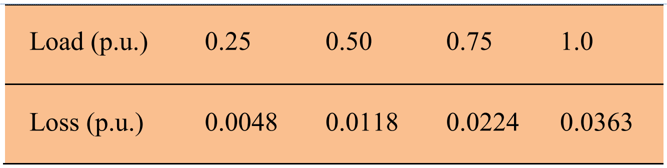
(a) Measured distribution loss data (p.u.) at multiple load levels (p.u)



(b) Interpolated model of distribution transformer losses.

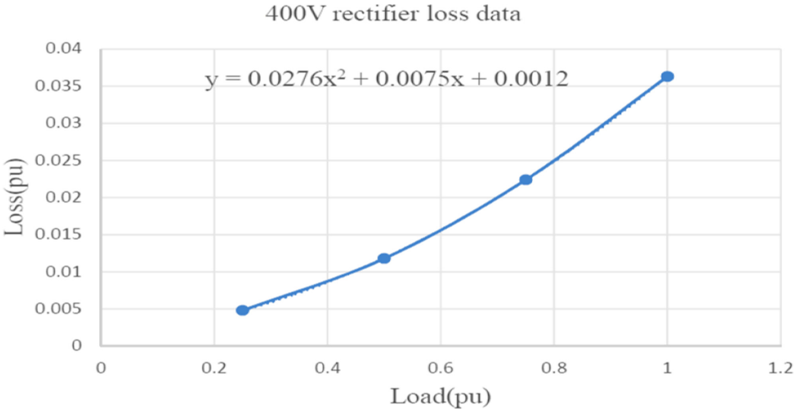
Fig. 8. Measured distribution loss and interpolated loss model

The loss data of 380 V DC rectifier is extracted from [21] and it is tabulated in Fig. 9(a).This loss data is based on a measured 400 V DC rectifier and has the following losses which is expressed in per unit value at different loading conditions. Similarly a regression analysis (or second order polynomial fit) was again done for this loss data and plotted in Fig. 9(b).



Load (p.u.)	0.25	0.50	0.75	1.0
Loss (p.u.)	0.0048	0.0118	0.0224	0.0363

(a) Measured 380V rectifier loss data (p.u.) at multiple load levels



(b) Interpolated model of rectifier losses

Fig. 9. Measured rectifier loss data and interpolated loss model

ii) Component Loss Coefficients: Regression analysis (or second order polynomial fit) had been done for all the loss data recorded. The no-load, proportional and square-law term coefficients for the components are listed in Table 7.

Table 7. No-load, proportional and square-law item coefficients

Converter	Loss item coefficients		
	*Kp*0	*Kp*1	*Kp*2
AC UPS	0.0892	−0.01096	0.11465
DC UPS	0.0152	−0.0029	0.0494
AC PSU	0.0601	−0.0933	0.1024
PV Inverter	0.0295	0.0033	0.0641
Distribution transformer	0.0029	−0.0015	0.0143
380 V DC rectifier	0.0012	0.0075	0.0276

5 Results and Discussions

5.1 Efficiency Analysis of Existing Distribution System (Base Case Scenario)

The efficiency analysis results of existing AC distribution systems is done by following the different component loss model described in above sections. The efficiency analysis of the data center for different load conditions was carried out based on multiplying the efficiency of the individual components used by the data center distribution system. By considering the efficiency plot of different equipment's used by the existing system at different load conditions, the total efficiency of the AC system is summarized in Table 8.

Table 8. Efficiency data of different components

Components	Efficiency (%) at multiple load level				
	25%	*50%*	*75%*	*100%*	*Average*
AC UPS	73.10	81.90	84.00	84.10	80.775
DC UPS	93.44	95.04	94.84	94.19	94.38
AC PSU	85.27	92.76	94.02	93.53	91.39
DC rectifier	98.12	97.69	97.11	96.50	97.36
PV Inverter	87.93	88.96	91.68	91.17	89.94
Distribution Transformer	98.44	98.87	98.75	98.45	98.63

Figure 10 shows the result of efficiency plot for the data center power distribution system (existing AC distribution system and the proposed DC system). The result demonstrated that the minimum efficiency is 61.4% at 25% load and maximum efficiency is 77.97% at 75% load condition. The average efficiency becomes 72.96%.

5.2 Efficiency Analysis of DC Distribution System (Proposed Case Scenario)

As a result the total efficiency of proposed DC power distribution system is based on the individual component efficiency. The following table is constructed to get the data points for total efficiency of the proposed system.

Figure 10 shows the result of efficiency plot for the data center power distribution system (proposed DC distribution system). The result indicated that the minimum efficiency is 80.6% at 25% load and maximum efficiency is 84.44% at 75% load condition. The average efficiency becomes 82.63%. Figure 10 compares the efficiency of AC and DC power distribution designs for various loading scenarios. In data centers, 380 V DC power distribution system is more efficient than a normal AC power distribution system.

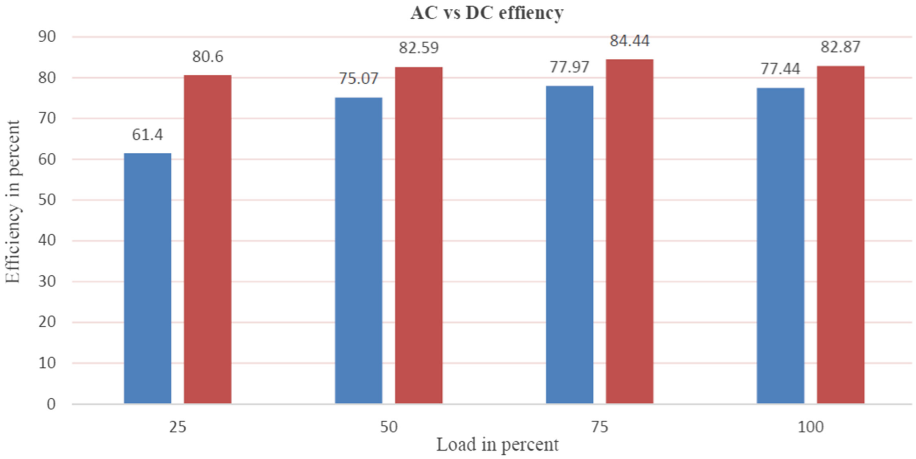


Fig. 10. Efficiency plot of AC and proposed DC distribution system.

Taking the average efficiency of both cases, a DC power distribution system is more efficient than AC power distribution architecture by 9.67%.

5.3 Energy Cost Analysis

The assessed Life Cycle Cost (LCC) of the arranged independent PV framework is portrayed in this segment. The lifetime cost of proprietorship and activity of an article, expressed in the present cash trade, is the LCC of that thing. Procurement, working, upkeep, and substitution costs are completely remembered for the expense of an independent PV framework.

The total present worth (PWs) of the costs of PV modules, storage batteries, battery charger, and inverter, the cost of installation, and the system's maintenance and operation cost (M&O) are all included in the LCC of the PV system. All of the products' lifetimes are estimated to be 25 years, except for the battery, which is estimated to be 5 years. Thus, an extra 2 groups of batteries (each of 2 batteries) to be purchased, after 5 years, 10 years, 15 years and 20 years, assuming inflation rate i of 3% and a discount or interest rate d of 10%.

Therefore, the LCC of the system can be calculated as the following equation.

$$LCC = C_{PV} + C_B + C_{B1PW} + C_{B2PW} + C_{B3PW} + C_{B4PW} + C_C + C_{Inv} + C_{Ins} + C_{MPW}. \tag{10}$$

And

$$C_{MPW} = \left(\frac{M}{yr}\right) x \left(\frac{1+i}{1+d}\right) x \left(\frac{1-\left(\frac{1+i}{1+d}\right)^N}{1-\left(\frac{1+i}{1+d}\right)}\right) \tag{11}$$

where,

C_{PV} - PV array cost
CB - Initial cost of batteries
CB1PW - Group of battery to be purchased after N years
CC-Charge controller cost
CInv - Inverter cost
CInst - Installation cost
C_{MPW} - maintenance cost

It is sometimes useful to calculate the LCC of a system on an annual basis. The annualized LCC (ALCC) of the PV system in terms of the present day dollars can be calculated using the following equation.

$$ALCC = LCC \times \left(\frac{1 - \left(\frac{1+i}{1+d}\right)}{1 - \left(\frac{1+i}{1+d}\right)^{N}} \right) \tag{12}$$

Hence,

Once the ALCC is known, the unit electrical cost (cost of 1 kWh) can be calculated, to be \$0.238/kWh, from Eq. (13).

$$Unit\,Electrical\,\mathrm{Cos}t = \frac{ALCC}{365E_L} \tag{13}$$

It is to be noted that this price is very high compared to the current unit cost of electricity in Ethiopia for 15 kV customer is 0.8008 Birr/kWh or **\$0.0235/kWh**. PV energy generation for data center is important due to its better efficiency and reliability to the power distribution system. This price is also free from interruption and fuel cost.

6 Conclusions

In this study the improvement method of data center's efficiency and reliability has been presented. A 380 V solar powered DC power distribution architecture has been proposed to obtain improved efficiency and better reliability in data center power distribution system. The design of solar power for overall data center loads has also been included. The efficiency analysis shows that solar powered DC distribution system is more efficient than the typical AC distribution system at different load levels. Results show that 380 V solar powered DC distribution has an average of 9.67% efficient than AC power distribution architecture of a selected data center for different loading level typically 25%, 50%, 75% and at full load (100%). This improvement is due to the reduction of number of convertors and high component efficiency of the proposed DC distribution system for a selected data center.

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