A Conditional-Constraint Optimization for Joint Energy Management of Data Center and Electric Vehicle Parking-Lot

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***Abstract*— In near future, the Electric Vehicles (EVs) will have a high level of penetration and their charging will be necessary to support daily operation. In such case, there will be three charging scenarios, such as (a) charging at commercial stations, (b) charging at home, and (c) charging at workplace. Therefore, during the working hours, the synchronized EV charging of the employee would experience an added demand charge on the data center operator. To reduce the impact of such demand charge, a joint power management strategy for the cloud data centers and its EVs parking-lot is required. However, the parked EVs is an energy source, such as battery bank that can participate in the power management problem. Considering the hybrid needs, in this paper a joint power management and energy cost minimization model for the data center and EV parking-lot is developed and solved as a conditional constraint optimization problem using Mixed Integer Linear Programming (MILP).**

Keywords*— *data centers; electric vehicles; smart grids; power outage; renewable energy

I. INTRODUCTION

In cloud data centers, the effective utilization of energy and the energy cost reduction are the focus of attention for the researchers. Therefore, attention towards Smart Grid (SG) has increased because of policy and regulatory initiatives for the advancement and deployment of relevant technologies. The data centers need to employ SG by considering its features and benefits for cost and energy efficiency [1]. The influence of the SG in data center operation provides: (a) saving on energy cost for the data center, (b) access to real-time states of SG (e.g. power availability, power price) and (c) temporal and spatial variations in renewable energy and electricity price [1]. The energy management of the data centers are categorized into inter-center and intra-center management [2]. Inter-center management deals with distribution of workload among geo-distributed data centers to reduce peak energy demand and operational cost, while intra-center management deals with the effective utilization of the energy resources and the distribution of workload among servers.

Several novel methodologies are aiming to enhance intra-center energy efficiency by introducing new algorithms and power saving circuits [3]. These techniques have a significant impact on the power consumption of the data center and cost minimization. However, the effective utilization of all available energy resources is another area that can efficiently ease the energy consumption of the data center. Another approach to perform cloud optimization, for example energy minimization and resource provisioning characterization of workload in cloud computing is essential [4]. The recent advancements brought diesel generators and renewable energy sources, such as wind, solar, biogas, and thermal energy into the SG. As a result, in recent years, the researchers have addressed the problem of intra-center energy cost optimization under the influence of SG environment [1], [5]. In [5], the authors proposed a novel Mixed Integer Linear Programming (MILP) based robust optimization to reduce the energy consumption cost of a data center on a day-ahead time horizon.

The penetration of the Electric Vehicles (EVs) in SGs is increasing gradually and a careful estimation states that by year 2030 more than half of the vehicles on the streets of America will be EVs [6]. It is expected that in future, there will be three scenarios of EV charging, such as charging at home, charging at commercial stations, and charging at workplace. Considering data centers where hundreds of people are employed, and they will also be using EVs as their main transport medium [6] this will result in increased energy consumption cost of the data centers. However, the batteries of the parked EVs can be considered as a massive installed battery bank during working hours. However, the cumulative/synchronous charging of the EVs pose more demand charges on the data centers operated under SGs [6]. In [7] the researchers focuses to reduce the operating cost of EVs. Therefore, a joint energy management and energy cost reduction strategy for the data center and their EVs parking-lot is required to be addressed. In this regard, in [8], a technique is proposed that discusses the power demand of the EVs that can fill the power valleys of the data center distributed geographically without altering power peaks and peak energy consumption cost. However, the authors have not explored the opportunity to use parked EVs as a viable energy source to reduce the peak energy consumption cost of the data centers.

In this paper, a joint energy management model for the data center and its EVs parking-lot is presented by extending the work of the robust energy management model presented in [5].

The model exploits the resources of the utility grid, renewable energy sources, battery bank, and backup power generators. The problem is formulated to maximize the number of EVs charged during working hours to meet owner's convenience. Moreover, a Mixed Integer Linear Programming (MILP) based conditional constraint optimization technique is developed to minimize the energy consumption cost of the data centers and EVs parking-lot. Furthermore, the optimization technique takes in consideration of the fully charged EVs to serve as a battery bank in intra-center power management if required.

TABLE 1
NOTATIONS USED IN THE SYSTEM MODEL

NOTATION	Definition
INDICES	
t	Length of time slot in hours up to $\mathrm{N} = 24$
$\imath$	Index for no. of diesel generators 1 to h
e	Index for the No. of EVs 1 to N_e
Constants	
$\mathrm{E}_b^{mini}, \mathrm{E}_b^{max}$	Min. and Max. energy storage bound on UPS batteries
p^b	Cost incurred by battery charging /discharging
P^{max}	Max. threshold on available grid power
$P_{ev}^{c}(t)$, $P_{ev}^{dc}(t)$	Charging and discharging power of the EVs batteries in time slot t
C^{EV}	Depreciation cost of the EV battery
Binary Variables	
$\mathcal{X}_c(t)$	1, if EVs are charging and 0 otherwise
$\mathcal{X}_{dc}(t)$	1, if EVs are discharging and 0 otherwise
Continuous Variables	
$\mathcal{P}_{\mathcal{DC}}(t)$	Data Center's total power consumption
$\mathcal{P}_{\wp}(t)$	Power purchased from the main grid
$\mathcal{P}_{\mathcal{S}}(t)$	Power sold to the main grid
$\mathcal{P}_{PV}^{s}(t)$	Total solar power generation
$\mathcal{P}_{wind}^{w}(t)$	Total wind power generation
$\mathcal{V}_{ev}(t)$	Open circuit voltage of an EV
$\mathcal{P}_{\mathcal{DC},b}(t)$	Data center power consumption benefit
$\mathcal{M}_b(t)$	Marginal benefit

II. INTRA-CENTER SYSTEM MODEL

The architectural overview of the intra-center system model is illustrated in Fig. 1. The notations and symbols used in the system model are given in Table 1. The intra-center system model consists of: (a) utility grid, (b) renewable energy resources including solar and wind power generation, (c) diesel generators, (d) DC batteries bank, and (e) EVs.

The renewable power resources and the main grid are considered as the primary sources of energy for the data center. Diesel generator, battery bank, and EVs are the dispatchable power sources. The data center interfaced with SG has two modes of operations, such as (a) grid connected mode and (b) grid islanded mode. In grid connected mode, the data center and EVs charging are powered from the main grid and renewable sources. In islanded/ power outage mode, the utility grid is islanded and the renewable energy resources, batteries bank, EVs, and diesel generators are the main energy sources. For extended power outage condition, data center needs to turn-on the cooling system and the backup generator will turn-on. The intra-center system consists of the following sub-systems.

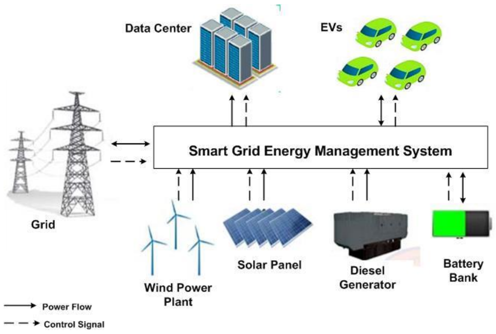

Fig. 1. The Architecture Intra-Center System Model

A. Power Consumption Model

Consider a data center with M homogeneous servers, where the idle and the peak power consumption of every server is identical for simplicity and the power consumption of a data center is computed as [9]:

$$\mathcal{P}_{\mathcal{DC}}(t) = m_{\mathfrak{s}}(t)[\mathcal{P}_i + (PUE - 1)\mathcal{P}_p + \left(\mathcal{P}_p - \mathcal{P}_i\right)\mathfrak{u}(t)] \quad (1)$$

In Eqn. (1), the $m_{\mathfrak{s}}(t)$ denotes the number of 'on' servers that are available for workload processing at time t. The terms $\mathcal{P}_i$ and $\mathcal{P}_p$ denote the idle and peak power of a server, respectively. The PUE is the power usage effectiveness that is as an active parameter to measure data center's energy efficiency and $\mathfrak{u}(t)$ is the CPU utilization of the data center in time slot t [9].

B. Modelling of the Renewable Energy Sources

The solar PV and wind are the renewable energy sources. The output power of a PV array is estimated on the bases of ambient temperature and solar irradiation [10].

$$\mathcal{P}_{PV}^{s}(t) = \begin{cases} \eta_{\mathcal{g}} \mathcal{A}_{\wp v} \mathcal{G}_{\wp v}(t) & z_{\mathcal{PV}}(t) = 1 \\ 0 & z_{\mathcal{PV}}(t) = 0 \end{cases}, \quad (2)$$

where s is the index of the PV array, the term $\eta_{\mathcal{g}}$ denotes the PV generation efficiency, the $\mathcal{A}_{\wp v}$ is the area of the PV generator (m^2), and the $\mathcal{G}_{\wp v}(t)$ is the solar irradiation (Wm^{-2}) of in titled module panel. To impose a check on solar generation, we introduce a binary variable $z_{\mathcal{PV}}(t)$. The value of the binary variable is 1, if the solar irradiation is within the upper and lower bound or 0 otherwise.

$$\mathcal{G}_{solar}^{min} \leq \mathcal{G}_{\wp v}(t) \leq \mathcal{G}_{solar}^{max}, \quad (3)$$

where the $\mathcal{G}_{solar}^{min}$ and $\mathcal{G}_{solar}^{max}$ are the lower and upper bounds of the solar irradiation, respectively. These upper and lower bounds depend on the range of the solar irradiation.

For the wind farm, we consider multiple identical wind turbines and the total power generated is the sum of the individual wind power generation system [10]. Therefore, the power generated by a single wind turbine is computed as:

$$\mathcal{P}_{wind}^{w}(t) = \begin{cases} \frac{1}{2}\rho \mathcal{A}_{\mathcal{b}} \mathcal{v}(t)^3 \mathcal{C}_{\wp} & z_w(t) = 1 \\ 0 & z_w(t) = 0 \end{cases}, \quad (4)$$

density, $\mathcal{A}_{\mathscr{b}} = \pi L^2$ is the blade area, $\mathscr{v}(t)$ is wind speed (m/sec), and $\mathcal{C}_{\mathscr{p}}$ is the power coefficient. The binary variable $z_w(t)$ is defined to check the generation of wind farm as the power generation will be zero, if the wind speed velocity is not within the cut-in and cut-out wind speeds.

$$V_{wind}^{min}(t) \leq \mathscr{v}(t) \leq V_{wind}^{max}(t), \tag{5}$$

where the V_{wind}^{min} and V_{wind}^{max} are lower (cut-in wind speed) and upper (cut-out wind speed) bounds on wind speed.

C. Diesel Generator Model

A piecewise linear cost model is considered to calculate the cost of diesel generator. Let $\mathscr{s}$ be the piecewise linear segment of non-convex diesel generator cost function [5]. For each linear segment there is a continuous variable $\mathfrak{p}_{\mathscr{s},i}(t)$ and binary variable $\mathfrak{B}_{\mathscr{s},i}(t)$. $\mathcal{P}_{DG}(t)$ is the total diesel generator power, that can be calculated as [5].

$$\mathcal{P}_{DG}(t) = \sum_{i=1}^{\mathfrak{N}} \left[\sum_{\mathscr{s}=1}^{n} \frac{\mathfrak{p}_{\mathscr{s},i}(t)}{\Delta T} \right], \tag{6}$$

where ΔT is the ‘on’ duration of diesel generator. The total power generation cost of diesel generators is formulated as:

$$\mathfrak{C}_{\mathcal{DG}}(t) = \sum_{i=1}^{\mathfrak{N}} \left[\sum_{\mathscr{s}=1}^{n} \left(\beta_{\mathscr{s},i}\mathfrak{p}_{\mathscr{s},i}(t) + \alpha_{\mathscr{s},i}\mathfrak{B}_{\mathscr{s},i}(t) \right) \right] + \mathfrak{S}_{\mathcal{DG},i}(t) \tag{7}$$

where i is the index of the diesel generator, $\beta_{\mathscr{s},i}$ indicates the slope, $\mathfrak{S}_{\mathcal{DG},i}$ represents the start-up cost of diesel generator, and $\alpha_{\mathscr{s},i}$ is the y-intercept of segments.

D. Battery Bank Model

In case of power outage, every data center has a battery bank backup and the power of batteries is affected by efficiency of the UPS charging or discharging. Let $\mathrm{E}_{\mathscr{b}}$ be the energy stored in the battery bank at time t. The terms $\mathcal{P}_{\mathscr{b}}^{c}(t)$ and $\mathcal{P}_{\mathscr{b}}^{dc}(t)$ are the charging and discharging power of battery bank of the data center. The energy level of the battery bank is computed as [1]:

$$\mathrm{E}_{\mathscr{b}}(t+1) = \mathrm{E}_{\mathscr{b}}(t) + \Delta T(\mathcal{P}_{\mathscr{b}}^{c}(t) - \mathcal{P}_{\mathscr{b}}^{dc}(t)), \tag{8}$$

where ΔT is the time slot. To ensure 100 percent uptime of the data center servers, the battery bank must be charged to a minimum power requirement; therefore, the energy storage level of the battery bank is ensured as:

$$\mathrm{E}_{\mathscr{b}}^{min} \leq \mathrm{E}_{\mathscr{b}}(t) \leq \mathrm{E}_{\mathscr{b}}^{max}. \tag{9}$$

The two binary variables $\mathcal{Y}_c(t)$ and $\mathcal{Y}_{dc}(t)$ are used to keep track the charging and discharging modes of the battery bank as batteries cannot be charged and discharged simultaneously; therefore, it follows the constraint as [1]:

$$\mathcal{Y}_c(t) + \mathcal{Y}_{dc}(t) \leq 1. \tag{10}$$

If the batteries are charging, then $\mathcal{Y}_c(t) = 1$ and $\mathcal{Y}_{dc}(t) = 0$ otherwise $\mathcal{Y}_c(t) = 0$ and $\mathcal{Y}_{dc}(t) = 1$.

E. Modelling of EV Parking-Lot

Suppose E_q is the minimal energy level of the qth EV parked in the parking-lot of data center $\mathcal{N}_{\mathfrak{d}}$. We assume that the data center's employees EVs are remained parked in the EV parking-lot for all working hours. The open-circuit computed as [11]: voltage of conventional lead acid battery of the EV is

$$\mathcal{V}_{ev}(t) = \mathcal{V}_{\mathscr{h}} + (\mathcal{V}_{\mathscr{h}} - \mathcal{V}_{\ell})*\mathcal{DOD}(t), \tag{11}$$

where $\mathcal{V}_{\mathscr{h}}$ is the open-circuit voltage when the Depth of Discharge ($\mathcal{DOD}$) equals to 0 and $\mathcal{V}_{\ell}$ is the open circuit voltage when $\mathcal{DOD} = 1$. The working hours are further divided into small time slots of length ℓ. At the start of each ℓth slot, the charge of the battery is estimated as [11]:

$$\mathcal{Q}(t) = \begin{cases} \mathcal{Q}_0 & t \leq 0 \\ \mathcal{Q}(t-1) + \mathrm{I}(t-1) * \ell & 0 < t \leq \mathrm{T}_{limit} \end{cases}, \tag{12}$$

where $\mathcal{Q}_0$ is the initial charge stored in the battery of the EV and $\mathrm{T}_{\ell imit}$ is the maximum charging time of the EV battery in hours. To make sure that all the EVs are adequately charged before leaving, a minimum charging current need to be maintained. The constraint on minimum current is defined as [11]:

$$\mathrm{I}_c(t) \geq \frac{\gamma * \mathrm{C}_{\mathcal{N}}}{\ell * \mathrm{T}_{\ell imit}}, \tag{13}$$

where $\mathrm{C}_{\mathcal{N}}$ is the battery capacity defined in Ampere hour (Ah) and γ is a constant positive term between 0 and 1, defined for the battery efficiency. Suppose there are N_e electric vehicles parked in the parking-lot and N_e^c are the number of EVs that required to be charged then the total aggregated power consumption of the EVs' parking-lot is computed as:

$$\mathcal{P}_{ev}^{c}(t) = \sum_{e=1}^{N_e^c} \mathcal{V}_{ev}(t) * \mathrm{I}_c(t). \tag{14}$$

Similarly, to compute the available power of the EV parking-lot, the N_e^{dc} number of EVs are computed that are maximally charged and available for an adequate time to be recharged again. The total available power of the EV's parking-lot is:

$$\mathcal{P}_{ev}^{dc}(t) = \sum_{e=1}^{N_e^{dc}} \mathcal{V}_{ev}(t) * \mathrm{I}_{dc}(t). \tag{15}$$

In Eqn. (15), the $\mathrm{I}_{dc}(t)$ is the discharging current of the EV battery that is computed using Eqn. (13); however, the $\mathrm{T}_{\ell imit}$ is adjusted such that none of the EV will be discharged in the last hour of the departure.

F. Power Management Model

To manage the power demand of the data center and EV parking-lot, the Eqn. (16) needs to be balanced.

$$\mathcal{P}_{\mathscr{p}}(t) - \mathcal{P}_{\mathcal{S}}(t) + \sum_{w=1}^{W} \mathcal{P}_{wind}^{w}(t) + \sum_{s=1}^{S} \mathcal{P}_{PV}^{s}(t) + \mathcal{P}_{DG}(t) - \mathcal{Y}_c(t)\mathcal{P}_{\mathscr{b}}^{c}(t) + \mathcal{Y}_{dc}(t)\mathcal{P}_{\mathscr{b}}^{dc}(t) - \mathcal{X}_c(t)\mathcal{P}_{ev}^{c}(t) + \mathcal{X}_{dc}(t)\mathcal{P}_{ev}^{dc}(t) = \mathcal{P}_{\mathcal{DC}}(t) \tag{16}$$

The upper and lower bounds are also imposed on the power purchased from and sold to the main grid, such as:

$$\begin{aligned} 0 \leq \mathcal{P}_{\mathscr{p}}(t) &\leq P_{\mathscr{p}}^{max}(t), \\ 0 \leq \mathcal{P}_{\mathcal{S}}(t) &\leq P_{\mathcal{S}}^{max}(t). \end{aligned} \tag{17}$$

where $P_P^{max}(t) \geq \left(\mathcal{P}_{\mathcal{DC}}(t) + \mathcal{P}_{\mathscr{b}}^{c}(t)\right)$ and $P_S^{max}(t) \geq \left(\sum_{w=1}^{W} \mathcal{P}_{wind}^{w}(t) + \sum_{s=1}^{S} \mathcal{P}_{PV}^{s}(t) + \mathcal{P}_{DG}(t) + \mathcal{P}_{\mathscr{b}}^{dc}(t)\right)$. The following decisions are made to balance the energy demand of the data center: (a) the power requisite from the main grid, (b) electricity purchasing and selling schedules in day-ahead power market, (c) battery bank and EVs charging and discharging schedule, (d) power generation by the diesel generators, and (e) maximum power utilization of renewable energy resources. The purpose is to minimize overall energy consumption cost.

G. Formulation of Intra-Center Cost Minimization

We developed a joint energy cost minimization model for data center and EV parking-lot under SG environment including power outages. The problem is formulated by considering the following prices: (a) electricity purchasing and selling from main grid, renewable energy resources, EVs charging and discharging, charging and discharging of battery bank, and backup diesel generators including startup cost. The objective function $\mathcal{C}^T(t)$ is defined in Eqn. (18) subjected to constraints with an aim to minimize the total energy consumption cost of data center and EV parking-lot. The formulation is cost incurred by electricity purchasing and selling from the grid (Term 1), power generation cost of the diesel generators (Term 2), depreciation cost of the battery bank due to charging and discharging (Term 3), depreciation cost of the EVs batteries due to charging and discharging (Term 4), minus the total benefit of the data center power demand (Term 5). The data center benefit function $\sum_{t=1}^{\aleph} \mathcal{P}_{\mathcal{D}C\_b}(t) + \mathcal{M}_b(t)$ used in this objective function is the one used and explain in Ref. [5].

$$\begin{aligned}\mathcal{C}(t) = \min\,[\,&\mathcal{C}^p(t)\mathcal{P}_{\wp}(t) + \mathcal{C}^{se}(t)\mathcal{P}_{\mathcal{S}}(t) + \\ &\mathfrak{C}_{\mathcal{DG}}(t) + (p^b(\mathcal{Y}_c(t)\mathcal{P}_{\mathscr{b}}^c(t) + \\ &\mathcal{Y}_{dc}(t)\mathcal{P}_{\mathscr{b}}^{dc}(t))) + C^{EV}((\mathcal{X}_c(t)P_{ev}^c(t) + \\ &\mathcal{X}_{dc}(t)\mathcal{P}_{ev}^{dc}(t))) - (\mathcal{P}_{\mathcal{D}C_b}(t) + \mathcal{M}_b(t))\end{aligned} \qquad (18))$$

Subject to

Eqn. (1) - Eqn. (17)

In Eqn. (19), the power purchase price $\mathcal{C}^p(t) \in \left[\mathcal{C}_p^{min}, \mathcal{C}_p^{max}\right]$ from the main grid, and power sold price $\mathcal{C}^{se}(t) \in [\mathcal{C}_{se}^{min}, \mathcal{C}_{se}^{max}]$ to the main grid are determined at the start of every time slot t and will remain persistent during time t and $\mathcal{C}^p(t) \geq \mathcal{C}^{se}(t)$.

III. CONDITIONAL CONSTRAINT OPTIMIZATION ALGORITHM

For the joint cost minimization problem of data center and EV parking-lot, we combined a conditional power management algorithm and MILP algorithm (constraint optimization technique) and develop a conditional-constraint optimization algorithm. It is known fact that operational cost of renewable power generation is minimal. The unavailability of renewable power source has a major impact on the overall energy consumption cost; therefore, in the light of above stated actuality, we consider two cases of operations in the algorithm: (1) when renewable energy sources are partially fulfilling the total energy requirement of the data center and EV parking-lot and (2) when renewable power generation is available in excess than the total power load. If available power of renewable energy resources is less than the power requirement of data center, then there exist following sub-cases:

- In grid connected mode, the algorithm aims to balance the power demand of the data center, EV parking-lot, and battery bank. On the bases of energy sources prioritization, the optimized joint energy consumption cost of the data center and EV parking-lot is computed using MILP. The flow of the algorithm is given in Fig. 2
- In grid islanded mode, the energy requirement will be fulfilled by the battery banks, charged batteries of the EVs and backup diesel generators. The flow is defined in Fig. 2.

If renewable energy is greater than the load of data center:

- In grid connected mode, the EVs and battery bank will be charged along with the conventional load of the data center.
- The algorithm will be modified according to the charging state of EVs batteries and battery bank of the data center and the excess energy will be sold to the grid.
- In grid islanded mode, the algorithm will reschedule the renewable resources to balance Eqn. (16).

All aforementioned models incorporated in this work are linearized first to solve the optimization problem using MILP framework. Due to this, the time complexity of algorithm is simply *O(1)+O(n)*. Considering the objective function in Eqn. (18), we have used the power balance equation as equality constraint, however in this work inequality constraints of EVs and battery bank have been considered. The bounds are applied on binary variables of power sources according to requirement.

IV. SIMULATION SETTING

We evaluate the performance of proposed algorithm based on real-time data. The following sub-sections summarizes the dataset and simulation settings for the proposed solution. The number of homogeneous servers, peak power consumption of a server, and idle power consumption of a server in the data center are considered as follow: $m\_\mathfrak{s}\,(t) = 15000, \mathcal{P}\_p = 240W\ , \mathcal{P}\_i = 168W$ [12][1].The CPU utilization data is obtained from the Google cluster data published by Google in 2011 that consist of about 12.5K machines [5]. In this paper, we only focus on CPU utilization considering that all servers are homogenous, i.e. the processing power of the servers is same. The data is normalized between 0 and 1. The CPU utilization of the data center is depicted in Fig. 3. The power consumption of the data center is computed using Eqn. (2) and also illustrated in Fig. 3.

The electricity pricing tariffs is taken from NYISO [1]. On pricing data traces, we calculate the average electricity cost per day for the three different areas. The electricity selling pricing is estimated as: $\mathrm{C}(t)^s = 0.9 * \mathrm{C}(t)^p$ [5]. The We consider wind turbine model V90 1.8MW in simulation. The specifications of model are as follows: $\mathcal{A}_b = 6079\,m^2$, $\rho = 1.23\,\frac{kg}{m^3}$, and $\mathcal{C}_{\wp} = 0.27$. For the wind turbine the cut-in wind speed is $4\,ms^{-1}$, rated wind speed average electricity price is shown in Fig. 4.is $14\,ms^{-1}$ and cut-out wind speed is $25\,ms^{-1}$ [5]. For solar power generation, we use the specifications of 250Wp PV-

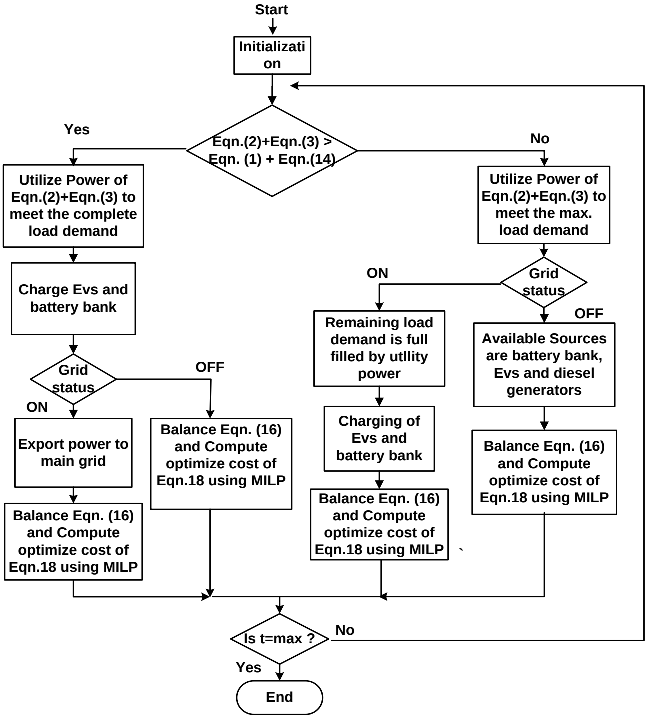

Fig. 2 Flow Chart of the Conditional-Constraint Optimization Algorithm

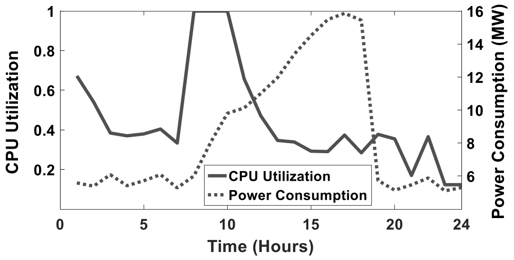

Fig. 3 CPU Utilization and Power Consumption of the Data Center

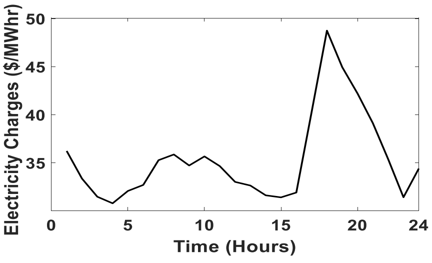

Fig. 4 Electricity Tariff for the Data Center

MLU250HC model of PV panel in the simulation. The solar irradiation is taken from National Solar Radiation Data Base (NSRDB) [13]. The backup generators must have enough capacity to fulfill the energy requirements of the data center, when a power outage occurs. Therefore, in the simulations the diesel generator model TP-C2000-T2-60 having 2MW capacity is used to power the data center electrical load [5]. Moreover, the start-up cost of the individual diesel generator is fixed at 2.75$/gallon [5]. Symmetra MW 16,00KW 480V 3-ph C&D Technologies UPS12-1000having valve-regulated lead-acid battery (VLRA) is considered battery bank to empower for data center computational load [5]. The charging/discharging rates of battery bank model is taken s $\mathcal{P}_{\mathscr{b}}^{c} = \mathcal{P}_{\mathscr{b}}^{dc} = 0.64$ MW and the cost of charging/discharging is considered as p^{b}= 0.1$/KWh [5].

We considered the EVs parked in the parking-lot with lead acid batteries, the specifications of the EV model are as follows: battery capacity 10kWh, fully charged and discharged voltage is 250V, maximum charging time is 8 hours, and maximum charging power is 6 kW [11]. Moreover, we assume that $V_{\hbar} = V_{\ell}$, which indicates that the open circuit voltage of the battery is invariable. The results should not be influenced significantly if we assume the battery to be fully efficient and all power to be transferred into the battery through the lossless charger.

V. PERFORMANCE EVALUATION AND DISCUSSIONS

This section evaluates and discusses the performance of the intra center cost minimization problem. Different cases are developed in different hours of the day in the data center to observe and evaluate the impact of individual energy sources on energy cost minimization.

A. Grid Connected Mode

The Fig. 5 illustrates the cost of the data center in grid connected mode. The grid connected operation involve the full utilization of the renewable energy resources and the remaining power is taken from the utility grid. The power consumption includes the data center's electrical load, charging of the battery bank, and the charging of the EVs. In Fig. 5, we can observe that the power consumption cost of the data center is nominal throughout the day. Moreover, during hours from 9-17 the renewable energy is in excess, the power is sold to the grid; therefore, the impact of cost is in negative.

B. Grid Islanded Mode

The impact of the grid islanded mode is also depicted in Fig. 5, where it is observable that the power consumption cost of the data center is relatively high at hour 2 compared to the grid connected mode of operation. At hour 2, the battery bank was unavailable for the data center due to low state of charge and the power requirement is fulfilled by the diesel generators. However, if the battery bank is initially charged to a certain level to provide a short duration backup for the servers, the inclusion of the diesel generators can be delayed further. This impact is also illustrated in Fig. 6 at hour 2 where a clear minimization in the energy consumption cost is observable.

C. Impact of Electric Vehicles Charging

The number of EVs associated with the data center are taken as 200. We assume that all EVs have arrived at 9:00 hours. and will leave at 17:00 hours. The algorithm makes sure that all EVs will be fully charged before they will leave the data center. The charging pattern of a randomly selected EV is shown in Fig. 6. power consumption cost of the data center under the grid islanded mode. During the hour 13, we intentionally islanded the grid and the algorithm balanced the power requirement of the data data centers via battery bank discharging power capacity of EV parking-lot, and diesel generators. There is a negligible decrease in the overall power consumption cost of the data center for hour number 13. To observe the impact clearly, a comparison is given in Table 2.

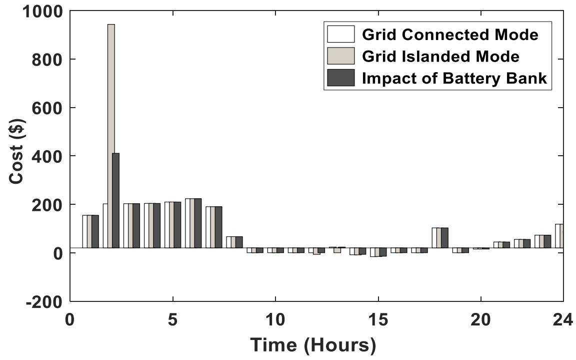

Fig. 5 Cost Analysis of Data Center under different operating modes

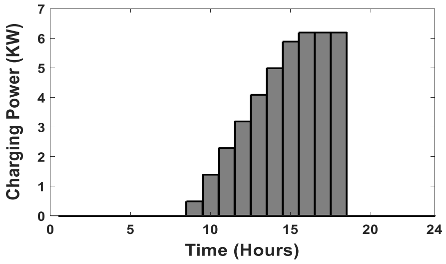

Fig. 6 Charging Pattern of a Randomly Selected EV during Office Hour

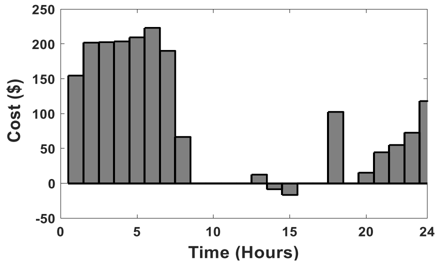

Fig. 7 Impact of EVs Discharging on Power Consumption Cost of Data Center

Table 2
The Comparative Analysis of Power Consumption Cost per Day

Modes of Operation	Cost Per Day
Grid Connected Mode	$ 1858.5
Grid Islanded Mode	$ 2178.6
Impact of Battery Bank along with Diesel Generator in Grid Islanded Mode	$ 2070.6
Impact of EVs Discharging	$ 1846.6

VI. CONCLUSIONS AND FUTURE WORK

In this research, we formulate an imperative and emerging problem based on energy cost optimization of the data center operated under SG along with the interaction of the EV parking-lot. We formulate a conditional constraint optimization algorithm to reduce the energy consumption cost of data center by considering the state of power outages under SG. Based on the proposed algorithm, we intended a strategy of joint energy management for EVs parking-lot and data centers. The simulation results on real-world data illustrate proposed strategy reduces energy consumption cost for the data center operator by 2.6%. In future, the cost minimization problem will be discussed by considering the different assumptions in wind speed and solar irradiation variables of renewable energy resources.

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