# MODELLING RENEWABLE ENERGY-BASED CLOUD COMPUTING ENVIRONMENT BY HARNESSING SOLAR ENERGY

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## ABSTRACT

Cloud computing is an emerging computational paradigm which is an integral aspect of Distributed computing. Cloud computing framework consists of integrated heterogeneous computing resources which are geographically dispersed which handles the different user queries for desired services and then outsource them to different spatially connected datacenters which performs the computing by utilizing the renewable/non-renewable energies. This article provides significant insights into foundations of Cloud Computing, its Architecture, features, and deployment and services model. We also discuss the renewable energy adoption to cloud computing. The high-power consumption and energy utilization with increasing carbon emission, the need for green energy powered data centers with renewable energy is the environment sustainable solution. Current trend of research is the different issues in adoption of solar energy resource to power the data centers in cloud computing. The primary challenge of migrating to solar energy powered cloud data centers is unpredictable, varying and infrequent nature of solar energy.

Index Terms—Cloud Computing, Datacenters, Renewable Energy, Solar Energy

## INTRODUCTION

Cloud computing is regarded as the powerful as well as flexible computing environment which is rapidly emerging now a days. Cloud computing provides on-demand online services at a cost-effective manner. Due to its flexible nature and modular architecture, it takes very less time to expand the services to a greater number of users. Cloud computing provides live-streaming of high-definition video, large audio, video as well as picture sharing, social networking activities of users, e-commerce and banking transaction of users. These data need to be stored in cloud and the users can access the data 24x7. There are many companies which provide cloud service providers. World renowned companies such as Google are the leading cloud service providers. These companies maintain cloud data centers (CDC) which is a state-of-the-art infrastructure which provides memory, processing capability as well as network storage to the users. The main functionality of the CDC is to store the massive amount of data generated by the users in a secured as well as modular framework. The CDC requires a significant amount of electricity to continuously run the servers as well as cooling facilities. The excess use of electricity is one of the major problems which also increases the cost of the day-to-day operations and maintenance. To reduce the significant cost of electricity, renewable energy sources are explored and most of the CDCs are migrating to renewable energy sources.

A lot of research is going on by the research community where the researchers are finding different cost-effective techniques to provide reliable and seamless electricity. Cost analysis of a cloud data center is provided in [1] where approximately 45% of the cost is for server and 15% cost is for electricity. Infrastructure for a CDC costs around 25% of the total budget whereas networking costs around 15%. To reduce the cost of electricity, renewable energy sources such as solar photovoltaic are explored. Some good review papers which explain the use of renewable energy sources in CDC has been provided in [2-4,8]. Future directions and a broad perspective of use of renewable energy has been explored in [3]. In [4]. The energy modeling in CDC has been explored. Solar energy purely depends on the solar irradiance falling on the surface. The technical aspects of measurement and estimation of solar irradiance on a particular geographical plane has been discussed in [5]. Different techno-economic aspects of installation, commissioning and operation of solar power plant for a specific location has been discussed in [6]. Energy efficient computing and CDC has been discussed in [7,9].

This article presents brief overview of using photovoltaic power plant for energy efficient CDC. Different technical and financial analysis for the same has been provided.

The article is organized in following manner. Section II discussed the basics of data centers and cloud computing framework; Section III presents the schematic photovoltaic system; Section IV represents the detailed technical design and financial aspects; Section V provides concluding remarks of this work.

**DATA CENTERS AND CLOUD COMPUTING**

Cloud computing is the emerging computing model that can be used to host geospatially connected heterogeneous computational resources outside of the cloud service provider's (CSPs) premises [11]. National Institute of Standard and Technology (NIST) proposed the definition of Cloud computing as a standard pay-as-you use model for providing easy, on-demand dynamic network access to a shared network of rapidly provisioned heterogeneous computing resources (such as networks, servers, storage, applications and services) that can be configured and dispensed as per demand with less interaction of cloud service provider [12, 13]. Therefore, as a popular technology paradigm, Cloud computing has a global userbase for accessing data and services [14]. Furthermore, Cloud computing has revolutionized the manner in which users work, collaborate and share knowledge locally and remotely with a large global userbase over the internet regardless of their physical presence [15].

Cloud can be viewed as a huge pool of connected shared and accessible virtualized computing and network resources which are geographically dispersed but connected. Resources of cloud can be dynamically reconfigured as per the incoming traffic from users (low to high), in order to provide better throughput and optimum resource utilization [16].

Figure 1 represents the fundamental cloud computing overview comprising of deployment models, delivery models, features offered and supporting elements to enable the cloud computing services.

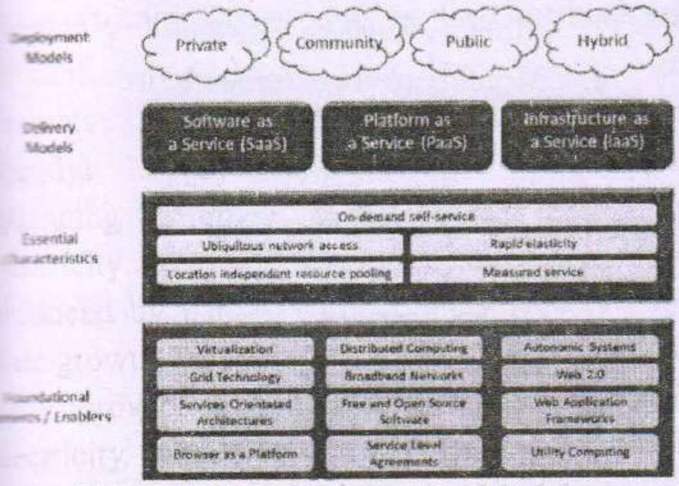

Figure 1. Cloud Computing Model

The Cloud datacenters perform the deployment of the cloud depending upon client/user requirement (single/multi-cloud deployment). Depending upon the nature of the services required by the clients / users, we can have four different deployment models for cloud environment, a) Public, b) Community, c) Private, d) Hybrid.

In public cloud, users access the desired services through web-based application interfaces which may be offered by internet browsers via web. Here the CSPs offer a standardized shared cloud framework to the users who are least bothered about the characteristics of the cloud they are using. Being less secure, the public clouds does seem advantageous by means of infrastructure cost. For organizations that cannot invest huge amounts in IT infrastructure and they deal with much of public data/information/content and less confidential data/information/content [17]. A community cloud is an integral framework to offer collaborative sharing of infrastructure and other IT Resources between multiple organizations having similar interests. It offers a lot of economic scalability to the CSPs and democratic equilibrium to the clients. The community cloud is overall managed and secured by all the associated organization or by CSPs [16]. Private cloud is provided by the CSPs for inter-organizational operation of an industry/company. Public cloud offers huge advantage of authorized access, enhanced security, easier maintenance and upgrades and organizational control over data/ information/ content usage/distribution. Non-public cloud can be analogous to computer network. Non-public one when compared to public cloud, In Public ones CSPs manage the applications and services provided, in Private cloud these services and applications are provided and corresponding resources are pooled along and shared for the users at the organizational level. The resources and applications in private cloud are managed solely by the organization [18]. Hybrid cloud is termed as a combination of multiple cloud variants (private, community, or public) which perform distinct functions but are integrated by regulated paradigm or licensed and certified framework that support portability of data and applications. [19].

Deployment Models of Cloud Computing offers different models such as Infrastructure as a Service (IAAS), Platform as a Service (PAAS), and Software as a Service (SAAS). a). Infrastructure as a Service (IAAS): In this model, Cloud clients utilize the underlying IT infrastructures (processing, storage, networks, and other fundamental computing resources) of the IaaS cloud. IAAS cloud enables "Virtualization" for integration/decomposing physical IT/Computational resources in ad-hoc manner to cater to the intermittent increasing or decreasing resource request/demand from clients/consumers of cloud. Typical example of IaaS is Amazon's EC2. b). Platform as a Service (PAAS): In this model, the software lifecycle which enables cloud clients to build their own cloud services and applications on the PaaS cloud. The principal disparity between SaaS and

PaaS model is that SaaS only provides/hosts fully developed cloud applications whereas PaaS provides/hosts both final and in-progress cloud applications. Example of PaaS is Google AppEngine. c). Software as a Service (SAAS): In this model, we have a development platform where the cloud consumers can launch own applications in a hosting environment, which can be shared and accessed through internet (e.g., web browser, PDA, etc.) by application clients. Typical examples of SaaS are SalesForce.com, Google Docs, and Google Mail.

Data Centers are typically a collection of servers with connected storage devices connected with a network of switches and routers. One of the major design challenges of datacenters is to minimize the operational energy usage. In Datacenters, the power and energy consumption by the computing infrastructure and associated cooling infrastructure which contributes primarily to the high energy cost and increasing carbon emission. The data centers energy consumption worldwide is estimated to be 26Gigawatt amounting to 1.4% of total global electrical energy usage with a 12% rate of growth per year [20], [21]. The Barcelona data center incurs a power usage billing of £1 million only per year which is sufficient to power of 1,200 homes [22]. The estimated overall carbon emission of cloud datacenters is 116.2 million metric tons of $CO_2$ in 2006 [23]. In 2010, Google datacenters consumed almost 2.26 million Megawatt hours of power, and resulted in carbon dioxide discharge of 1.46 million metric tons of $CO_2$ [24].

## PHOTOVOLTAIC SYSTEM

To install a photovoltaic based system to generate electricity in a specific location, different details need to be found out[10].

1. Latitude and longitude of the location
2. Monthly average solar insolation
3. Monthly average sunshine
4. Monthly average temperature
5. Monthly average perspiration

From the above data, different parameters are found out [10]. Some of the parameters are

1. Global horizontal irradiance (GHI)
2. Direct horizontal irradiance (DHI)
3. Direct normal irradiance (DNI)

From the above data and calculated parameters, a decision can be made whether to install a PV plant or not. Figure 2 provides the annual profile of different parameters for solar irradiance[10].

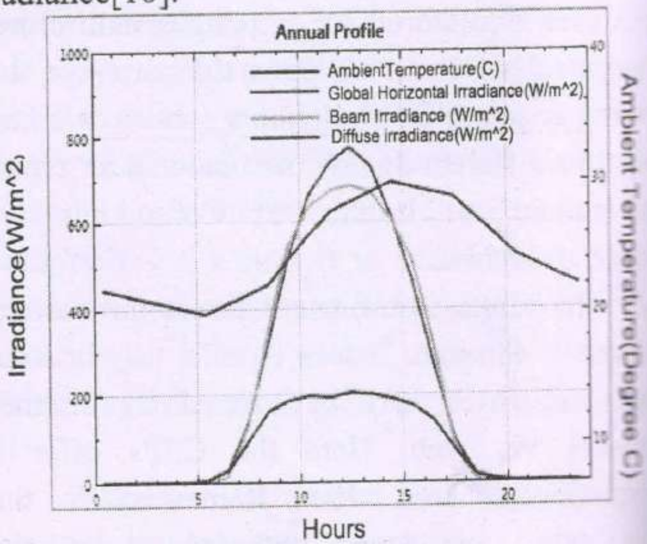


Fig. 2. Annual profile of different parameters for solar irradiance

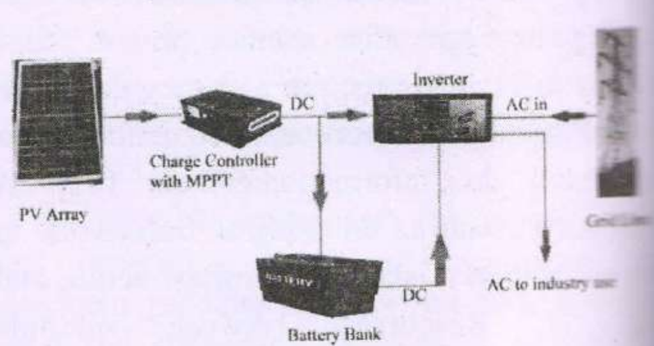


Fig. 3. Grid connected PV System

Figure 3 provides the schematic of grid connected PV system which comprises of PV array, charge controller with MPPT, inverter and battery bank. Battery bank is used for back up purpose [10].

Solar system comprises of different power converters which is used to process the voltage generated by solar panel or PV panel and power up the electrical load (DC or AC). The voltage produced by solar panel is varying in nature due to variation in solar irradiance and ambient temperature. For maximizing the solar panel power, the algorithms for maximum power point tracking (MPPT) are used. There are various MPPT schemes but perturb & observe (P&O) MPPT is one of the most efficient. The output of MPPT is provided to the DC-DC power converter which changes the duty cycle according to the input voltage. Figure 4 provides schematic representation of PV system with MPPT and load [10].

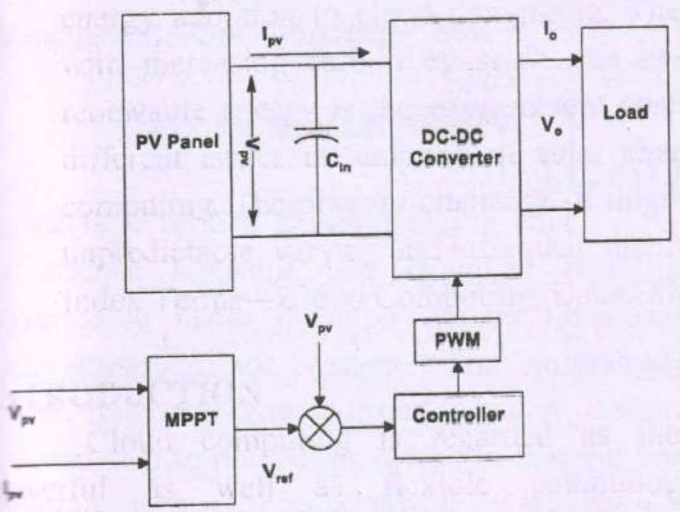


Fig. 4. Block diagram of Solar PV system with MPPT and DC-DC converter

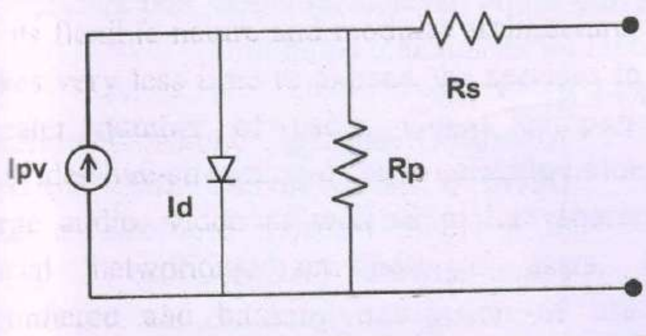


Fig. 5 Equivalent circuit diagram of solar cell

From Figure 5, the I-V characteristics [10] of an PV cell(ideal) may be represented as

$$I = I_{pv} - I_o\left[\exp\left(\frac{qV}{akT}\right) - 1\right] \quad (1)$$

Where $I_o$ is the diode leakage current, $q$ denotes charge of electrons, $K$ denotes Boltzmann constant and $T$ denotes p-n junction temperature in Kelvin. Analytically, PV cell series and parallel equivalence may be denoted as:

$$I = I_{pv} - I_o\left[\exp\left(\frac{qV}{akT}\right) - 1\right] - \frac{V + R_s I}{R_p} \quad (2)$$

Where $R_s$ denotes resistance in series and $R_p$ denotes resistance in parallel, $V_t$ denotes PV cell thermal resistance and $N_s$ denotes the total number of PV cells available in series connection. $V_t = \frac{N_s kT}{q}$ denotes the PV cell thermal resistance. The solar irradiance and temperature represent the determinant factors for PV cell current. The following equation represents the relation between the current, temperature of PV cell,

$$I_{pv} = \left(I_{pv,n} + K_I \Delta_T\right)\frac{G}{G_n} \quad (3)$$

where $I_{pv,n}$ denotes light generated current at nominal operating condition (25°C,1000W/m$^2$), $\Delta_T$ represents temperature difference (Actual and nominal), $G$ represents the surface irradiance of PV cell and $G_n$ represents the nominal irradiance PV cell.

The saturation current of the diode and temperature can be related as:

$$I_o = I_{o,n}\left(\frac{T_n}{T}\right)^3 \exp\left[\frac{qE_g}{ak}\left(\frac{1}{T_n} - \frac{1}{T}\right)\right] \quad (4)$$

The expression for nominal saturation current is:

$$I_{o,n} = \frac{I_{sc,n}}{\exp\left(\frac{V_{oc,n}}{aV_{t,n}}\right) - 1} \quad (5)$$

The modified nominal saturation current and its Simulink model can be represented as

$$I_{o,n} = \frac{I_{sc,n} + K_V \Delta_T}{\exp\left(\frac{V_{oc,n} + K_I \Delta_T}{aV_t}\right) - 1} \quad (6)$$

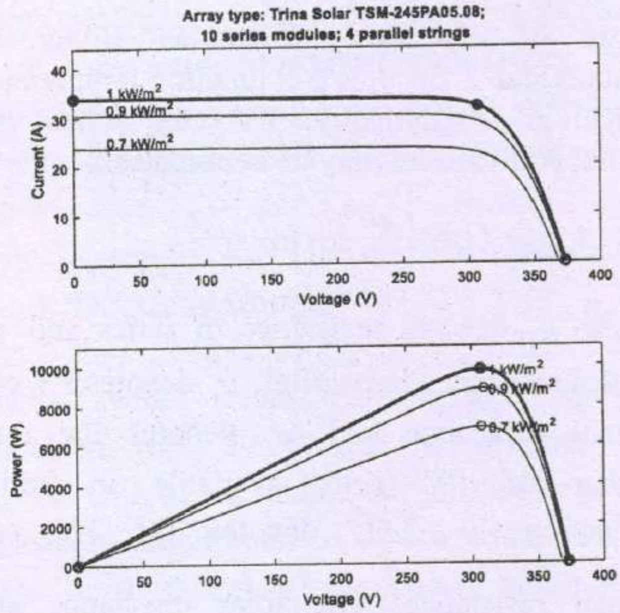


Fig. 6. V-I and P-V characteristics of solar panels with varying solar irradiance.

Figure 6 provides the V-I and P-V characteristics [10] of PV panel with varying solar irradiance. Due to variation in solar irradiance, the voltage output is also variable. So different MPPT technique and DC-DC converters are utilized to make the voltage stable, Figure 7 illustrates the flow chart of P&O MPPT [10].

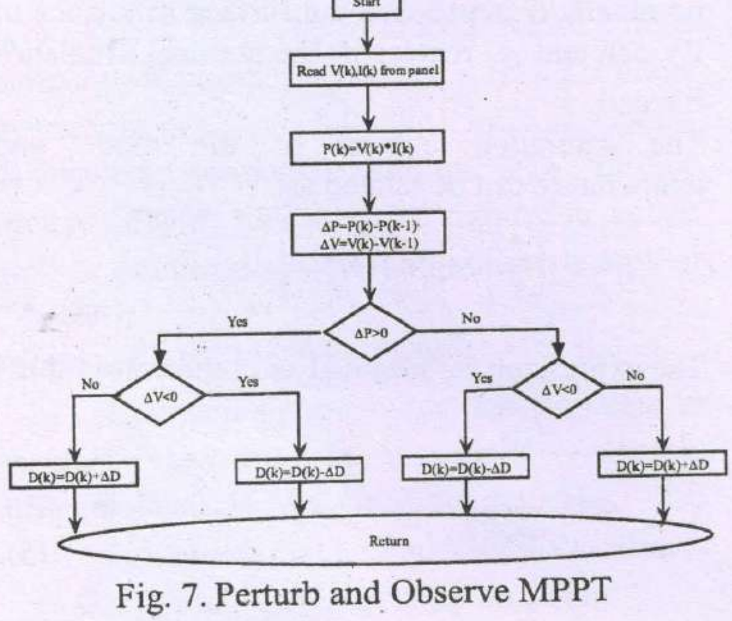


Fig. 7. Perturb and Observe MPPT

## TECHNICAL DESIGN AND FINANCIAL ASPECTS

There are different technical design aspects of solar PV system [10]

Generation factor for Panel

PV module total Watt peak power rating

Requirement of total number of PV modules

Sizing and rating of inverter

Sizing of the battery

To install a PV power plant, land is required according to the size of the PV plant. Different financial aspect of design power plant is shown below [10]

a. Cost of each PV module
b. Cost of each inverter
c. Labor cost for design
d. Labor cost for installation
e. Fixed operation and management cost
f. Variable management cost

## CONCLUSION

This article presents a brief analysis of different technical and financial aspects of renewable energy powered cloud datacenters. Harnessing solar energy for operating data centers reduces harmful environmental effect and the cost of energy utilization of data centers. We suggest PV power based solar energy system with its different parameters to augment the datacenter operation so that it is cost effective for the cloud service providers and it offers a model for sustainable computing.

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