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Economic Viability of Smart Grid Cloud in India

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Abstract

While the innovation and technology is modernizing the industry at rapid pace, the electrical power system is lagging behind the race and is being maintained in the same way for decades. Although the smart grid has ensured demand-response, reduction in transmission and distribution losses, and minimized theft, the inherent characteristic of enormous data generation has become a biggest concern. The absence of IT infrastructure in existing set up for handling unstructured data and huge capital investments are the major obstacles in complete success of smart grid in developing countries like India. However cloud computing has emerged as a solution to this problem. In this work, we have simulated cloud for smart grid on CloudSim and derived the cost for storing the smart grid data on cloud. The total cost of ownership (TCO) and return on investment (ROI) on building the datacenter with same configuration is also calculated using net present value (NPV), and compared with previous calculated cost. The results indicate that the initial cost of building a datacentre is $6673185 and ROI is 22.74 % in 7 years, which is low keeping in view the fact that during average design life of 10 years, a datacenter undergoes major equipment changes 3 to 4 times. On the contrary, outsourcing the same data on to cloud costs $2430720 annually, which is considered as an effective alternative. This analysis would be beneficial to developing countries like India in framing policies for storing the smart grid data on to the cloud which will further help in reaping the benefits of smart grid.

Keywords: *Cloud computing; smart grid; CloudSim; net present value; return on investment.*

1. Introduction

Utility computing has attracted the attention of researchers and academia with the idea of using computing services as a commodity that can be delivered like other utilities *e.g*. electric and telephone. New innovations in hardware (processor technology); in software (optimized algorithms) and in computing paradigms (cluster computing/grid computing), have fulfilled the growing demand of high processing power. Internet, the global system of interconnected devices that used TCP/IP suite for interconnection, acted as a precursor to cloud computing. Cloud computing is a recently evolved computing technology which provides on demand access to network of computing resources (compute servers, storage servers, software and applications) over the internet through pay per use model [1-3]. By shifting the IT applications from captive datacenter to scalable, shared infrastructure provided by cloud, the organizations can concentrate on adding business value by renewed focus on core activities. The resources can be dynamically provisioned, depending upon service-level-agreements (SLA) mutually agreed upon between the service provider and the customer. Cloud computing services can be categorized

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into three classes, according to the abstraction level of the capability provided and the service model of providers, namely: (1) Infrastructure as a Service (IaaS), (2) Platform as a Service (PaaS), and (3) Software as a Service (SaaS).

The advantages like on-demand computing, ubiquitous computing, pay-per-use model and location independent pooling of resources, have encouraged the organizations to shift their businesses on to the cloud. Today, cloud computing finds its application in number of fields namely education, research, medical, banking, entertainment *etc*. Another field of application can be the power sector. Smart grid is the next generation electricity grid, which has evolved through the integration of information and communication technology into electricity transmission and distribution (T&D) networks. Smart grid is the maximum optimization of energy management achieved through T&D automation, efficient use of existing network and integration of smart devices. Smart grid's realization holds the potential to move nation's electric system from a centralized, producer controlled network to a less centralized, more consumer-interactive and more environmental responsive model. The reference model provided by NIST has divided the smart grid into seven domains: customers, markets, service providers, operations, bulk generation, transmission and distribution [4].

The smart grid requires scalable storage servers for data generated by smart sensors. Compute servers are needed for hosting analytic tools and optimization algorithms to carry out self-healing, fault tolerance, load balancing [5] and demand response functions. Additionally, the web servers are required for hosting customer web applications to display real-time consumption patterns, flexible tariffs and online bill payments. It is estimated that the smart grid will generate 22 gigabytes of data each day from its 2 million customers [6]. Scalable storage and compute servers are required to manage the enormous data generated from country's smart grid. Due to electric power system's own characteristics, it cannot store energy on a large scale. The electric generation, transmission, distribution and usage processes must be executed simultaneously. So, a fast, efficient and dependable communications infrastructure is required for secure, reliable and economic power supply. The powerline communications (PLC) is emerging as a key medium for exchanging the information between the utilities and end users. But, skeptics argue that PLC has an unclear standardization status and offers data rates that are too small. Others also contend that PLC modems are still too expensive and that they present electromagnetic compatibility (EMC) issues [7]. Cisco also recommends independent IP based network for interconnecting seven domains of smart grid [8]. Energy deficit is also a major challenge in traditional grid system. India experienced overall energy shortfall and peak shortage of 10.1% and 12.7% respectively during financial year 2010-11, while the anticipated overall energy shortfall and peak shortage for financial year 2014-15 is 5.1% and 2% respectively [9]. It is estimated that judicious management of power can fulfil the 80% electricity demand of the country. The T&D losses, theft and billing deficiencies are the other challenges faced by the grid. Thirteenth Finance Commission (TFC) reported the net loss of Rs. 68,643 crore in FY 2011-12 and has projected the widening of consolidated net loss at Rs 1,16,089 crore in FY 2014-15. Cloud based intelligent monitoring and control systems can minimize the AT&C losses by improving metering efficiency, proper energy accounting & auditing, improved billing & collection efficiency, planned expansion of distribution lines, preventing theft & pilferages and overloading of the system.

Inadequate computing infrastructure in existing setup and financial constraints are the primary obstacles in full implementation of smart grid in developing countries like India. The appliance of the cloud computing model meets the requirement of data and computing intensive smart grid applications. But before making any capital investment decision for implementing cloud for storing smart grid data and applications, a detailed analysis of all the parameters namely cost of owning, maintaining, operating and disposing of a project must be considered. More importantly, the critical factor to be considered while analyzing the cost is the time value of money. That is because money has real earning potential over time among alternative investment opportunities, and future revenues or savings always carry some risk. The time value of money is calculated using discount rate. It is the rate used to discount future cash flows to the present value. The following measures have been used in this research to analyze the investment decision to build captive datacenter for storing data of smart grid of India: total cost of ownership (TCO), net present value (NPV) and return on investment (ROI). TCO is an estimate of the total costs of infrastructure, services and construction works over the entire life period of the project. NPV is defined as the aggregate of the present values (PVs) of incoming and outgoing cash flows over a period of time. ROI is a measure that investigates the amount of additional profits produced due to a certain investment. On the other hand cost of handling same data on cloud has also been estimated using CloudSim. These two costs are compared to check the hypothesis whether storing smart grid data on cloud is economically viable or not. The limitation of this work is that it simulates the cloud for smart grid of India, managed by PowerGrid Corporation of India, which has point of presence in 68 cities. Since it is not fully evolved, so thin client based model [10] is implemented and only data from 68 substations upto the range of 585 GB is fetched.

The remainder of the work is organized as follows: Section 2 presents the background and the related work. Section 3 describes the method and procedure. The CloudSim simulator, LCCA, TCO, NPV and ROI are discussed in this section. Section 4 presents the results and discussion section. Finally, we conclude and give future research direction in Section 5.

2. Background and Related Work

There have been several studies on how smart grid applications can exploit cloud computing to increase their reliability and performance [11-12]. Mehmi *et al*. have proposed smart grid cloud for Indian power sector that fetches and store data from bulk power generation centers, transmission substations, distribution substations and markets. Based on analysis of data, it performs distribution operation & control, transmission operation & control, distributed generation operation & control, self-healing, fault tolerance and demand side management functions [13-14]. Yigit *et al*. have discussed smart grid & cloud computing architectures, cloud platform's technical & security issues, and opportunities & challenges of cloud platforms for smart grid applications [15]. The existing cloud computing based smart grid projects and applications are also highlighted. In another study, Ugale et.al proposed an internet connectivity device model instead of having C.P.U. and discs, for cloud computing model for smart grid applications [10]. Tsai and Hong *et al*. presented a review of classification and clustering algorithms for smart grid to provide a blueprint for enhancing the intelligence of smart grid [16]. Dong *et al*. have studied the characteristics of cloud and discussed on how to build a SPUSS (Smart power utilization service system) [17]. Based on simulation techniques, it has been shown that a grid-aware service request routing design in cloud computing can significantly help in load balancing in the electric grid and making the grid more reliable and more robust with respect to link breakage and load demand variations [18]. Seo and Jung *et al*. presented a cloud computing architecture for discrete event system modeling and simulation [19]. Ahat and Bui *et al*. have used mathematical tools such as complex networks theory and game theory to model the smart grid and ecodistricts [20]. Nunez *et al*. presented the simulation model using iCanCloud [21]. Haselmann and Vossen acknowledged the importance of return on investment (ROI), net present value (NPV) and total cost of ownership (TCO) while assessing the economic value of cloud sourcing by small and medium-sized enterprises [22].

Our research distinguishes itself from work cited above by addressing the unique requirements of the domain. Firstly, although the above researches have proposed the cloud computing model for smart grid, a simulation cloud for smart grid is largely missing. Secondly, there are number of cloud simulators available for research but not much research on CloudSim for simulating smart grid's IT infrastructure, has been found. Thirdly, economic viability study for smart grid cloud using NPV, TCO and ROI is generally missing in all literatures.

3. Method and Procedure

3.1. CloudSim: A Framework for Modeling Cloud Computing Infrastructures and Services

The CloudSim is a new, generalized, and extensible simulation framework that enables seamless modeling, simulation, and experimentation of emerging cloud infrastructures and application services [23]. It enables the modeling of datacenter, hosts, VMs, cloudlets and brokers. Datacenter can be modelled to host similar or varied configuration servers. The hosts on datacenter can be configured on the basis of following characteristics: host id, RAM, storage, bandwidth, processing power and number of attached processing elements (PE). The hosts are responsible for managing the VM creation, VM migration, VM destruction and VM provisioning. The allocation of VMs to host depends upon the allocation policy adopted by VM provisioner, default policy being first come first serve. The applications or service requests in form of cloudlets are handled by VMs that are allocated a share of processing power and memory on datacenter hosts. The number of VMs created on a host depends upon the VM RAM. The VMs are characterized by image size, RAM, processing power, bandwidth and number of CPUs, while the cloudlets are characterized by length, file size, file output size and number of CPUs. Cloudlet length specifies the instructions need to be executed to get the task done. The input file size indicates the size of source code of cloudlet and input data while cloudlet output size indicates the cloudlet file size and output data. The host can be configured to utilize the time-shared or space-shared policy or customized policy for cloudlet mapping to VM. Do and Rotter compared several scheduling algorithms from the aspect of the average energy consumption and heat emission of servers as well as the blocking probabilities of on-demand requests [24]. Application of efficient algorithms and information processing in real cloud can decrease the environment effect [25]. The cloud market is simulated by associating the cost per memory, cost per storage, cost per bandwidth and processing cost with the datacenter. The VM creation for applications will incur memory and storage costs while the bandwidth costs will incur during the transfer of data. If no task is executed on VM after its creation, then only storage and memory costs will be charged from the user.

In the design of experiment, simulation has been done for cloud computing model for smart grid of India. Power Grid Corporation of India Limited (POWERGRID), the Central Transmission Utility (CTU) of the country under Ministry of Power, is one amongst the largest power transmission utilities in the world. The corporation has an intra city network in 68 cities and point of presence in approximately 178 cities [26]. So, cloud is initially created using CloudSim for POWERGRID's existing smart grid network of 68 nodes (cities) and has been extended to 178 cities (Figure 1). However, this cloud is flexible enough to accommodate more nodes (cities). The data is fetched in the form of cloudlets from thin clients representing the nodes. In our experiments, we have taken two scenarios. First, we have taken the service from 1 CSP and in second we have created the cloud federation where service from 2 CSPs is taken. The number of hosts created on each data center is 10 where each host has configuration of 5 GB RAM, 1000 GB of storage and bandwidth of 1Gbps. Each VM has characteristic of 256 MB RAM, 250 MIPS, 10 MB bandwidth and image size of 10000MB. The cloudlets have the characteristics of 300 MB file size and output file size of 300 MB. The no. of cloudlets is varied from 200 to 1000 to investigate effect on cost. The data transfer vari es between 117 GB to 585 GB.

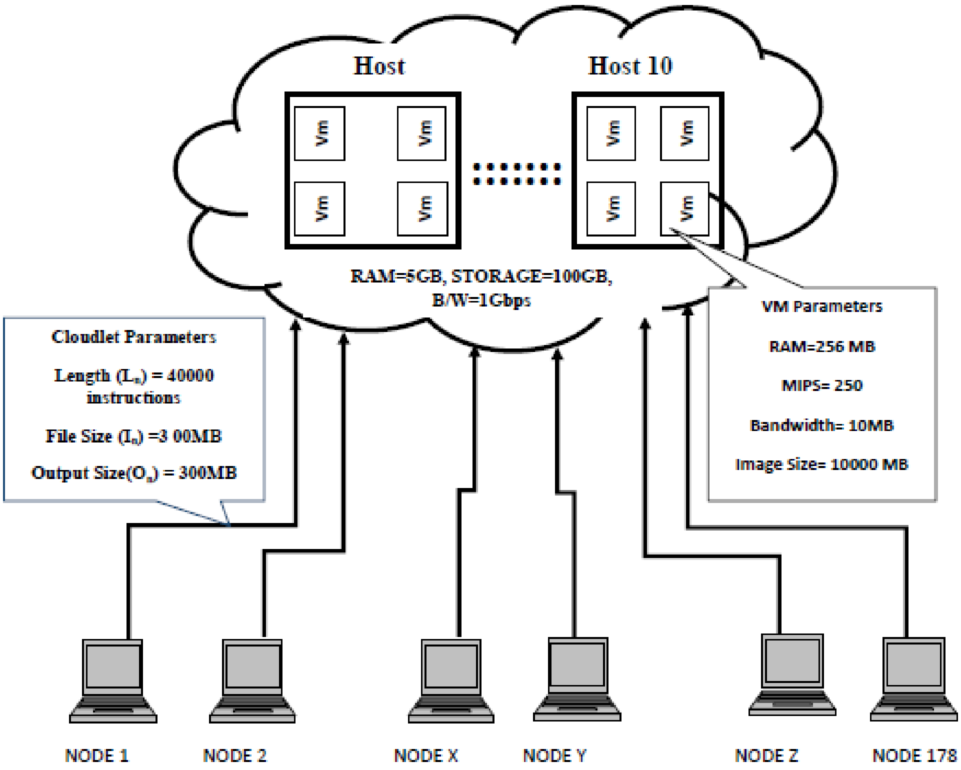

Figure 1. Simulation Model for Smart Grid Cloud on CloudSim

3.2. LCCA, TCO, NPV & ROI

The life cycle cost analysis (LCCA) is an important economic tool for evaluating the capital investment decision for any project in which all the cost of owning, maintaining, operating and disposing of a project are considered significant. It is the aggregate of PVs of all the costs (investment costs, installation costs, capital costs, financing costs, opportunity costs and disposal costs) over the lifetime of project. This analysis is beneficial in exploring the alternative designs for a project which although fulfills the performance parameters but may have contrasting investment, operating, maintenance, or repair costs and possibly different life spans. The analysis investigates the future value of any project investment that has been made today. It is an important method to evaluate the cost of project especially datacenter over its life time, calculate the ROI and decide the investment based on true costs versus initial costs. LCCA can also help the administrators to make decisions about design, location, infrastructure placements, addition or replacement of infrastructure, investment priorities and budget allocation *etc.* As the data center industry is marked with fast technological changes and uncertainty of future needs, the LCCAs objective approach can overcome these problems by making the impartial and informed decisions. LCCA has the following features [27]:

- It provides the authentic measure of the overall cost-effectiveness of design alternatives through its inherent precise, analytical, unbiased and objective approach.
- It provides authentic data that can justify the decision.
- It provides the alternatives to reduce the total cost of ownership.

In finance, the net present value or net present worth is defined as the aggregate of the PVs of incoming and outgoing cash flows over a period of time [28]. The incoming and outgoing cash flows are also known as benefit and cash flows, respectively [29]. It has been found that time affects the value of cash flows. For example, if a person invests $100 with the assurance of $110 return after one month, then return assurance of $110 after 3 years would not be a safest investment as it would be worth much less today to the same person, although the return was equally assured. The reduced current value of future cash flows depends upon various market parameters like market driven rate of return. Technically, the equal valued investment fetches different returns over a time-series. For example if there exists a time series of identical cash flows, the cash flow in the present is the most valuable, with each future cash flow becoming less valuable than the previous cash flow as the present return can be invested immediately in other projects while the future returns can't be. For comparing the competing design models, all costs and benefits are normalized to the same point in time. NPV is calculated by converting costs and benefits to either present value or annual value. A negative NPV indicates the loss while positive NPV indicates profit in investment. NPV proves that although a project/design can deliver profit, it may not claim as the best investment option. The NPV formula is commonly used to appraise the PV and the ROI over longer periods of time [30]. It does this by discounting the future, or taking into account the time value of money. This is the preferred method used to determine the true ROI in present terms.

$$\text{FV} = \text{PV}\left(1+i\right)^{t} \tag{1}$$

Where FV = Future Value, PV = Present Value. i = discount rate and t = number of interest periods

The NPV can be calculated by following formula.

$$NPV\left(i,N\right)=\sum_{t=0}^{N}\frac{R_t}{\left(1+i\right)^{t}} \tag{2}$$

R_t = net cash flow *i.e.* cash inflow – cash outflow, at time *t*

It can also be written in a continuous variation

$$NPV(i)=\int_{t=0}^{\infty}\left(1+t\right)^{-t}\cdot r\left(t\right)dt \tag{3}$$

Where *r* (*t*) is the rate of flowing cash given in money per time, and *r*(*t*) = 0 when the investment is over.

Return on investment is a measure that investigates the amount of additional profits produced due to a certain investment. Businesses use this calculation to compare different scenarios for investments to see which would produce the greatest profit and benefit for the company. ROI can be calculated by following formula

$$\text{ROI} = \frac{\text{NPV}}{(\text{Initial Investment Cost})} \quad (4)$$

The purpose of ROI varies and has following features [31]:

- Helps organizations to fix priorities and justifications to projects.
- Provides rational and facilitate informed choices about future investment/ merger/acquisition decisions.
- Analyzes the ongoing projects and evaluates the post-implementation phase.
- Facilitates decisions based relevant facts within the process of evaluating existing projects.
- Management of the business units and evaluation of the individual managers in decentralized companies.

Some researchers consider that ROI evaluations have even greater impact on project development. It is a process of getting everybody's attention to the financial aspects of the decisions and stimulating a rigid financial analysis. Chief Information Officers (CIOs) favour the use of ROI because that's the way to show that IT departments are profit centers, not just cost centers, as it may seem when total cost of ownership (TCO) is used as a metric [32].

Total Cost of Ownership (TCO) is an estimate of the total costs of infrastructure, services or construction works over the entire life period of the project. According to Mieritz and Kirwin, TCO is the holistic view of costs across enterprise boundaries over time [33]. It includes the initial investment plus all other costs that will be incurred throughout the project, less any income that is generated. TCO can be used at following stages [34]:

- In a business case to assess the costs, benefits and risks associated with the investment.
- When comparing different business projects, models, maintenance options or solutions on a comparable cost basis.
- To investigate the different cost parameters in the life span of a project.
- By a supplier when bidding for a contract to demonstrate the total benefits and value being offered – especially where the initial purchase price is higher than competitors, but the total cost of ownership is lower.
- In selecting the best supplier by assessing the comparative whole-of-life costs of competing bids.
- In managing the contract to track actual expenses and income against budget.

The prerequisite, while comparing the costs between captive data centers and cloud computing, is accurate investigation of the true costs of both options. It's important to note that, major quantum of costs in case of cloud computing accounts to operational costs (Opex) which can be easily assessed; this is due to a number of reasons:

- Competitive markets have instilled transparent pricing based on infrastructure namely storage, RAM and bandwidth usage.
- Usage price is generally fixed per unit of time. Cloud customers can easily calculate the costs of deploying and running their applications as per the usage.

In contrast, the cost calculation in case of captive data centers accounts to upfront costs (Capex) which is quite difficult to calculate as it fails to take into account the following costs [35]:

- The direct costs that accompany running a server: power, floor space, storage, and IT operations to manage those resources.

- The indirect costs of running a server: network and storage infrastructure and IT operations to manage the general infrastructure.
- The overhead costs of owning a server: procurement and accounting personnel, not to mention a critical resource in short supply: IT management and its attention.

All of these hidden costs make a direct cost comparison difficult. However TCO calculations can be derived using the APC TCO calculator software application [36], which is developed and maintained by the Availability Science Center of APC. The TCO calculator takes into account the average costs of equipment, installation, design engineering, facility engineering and project management costs. The equipment costs include cost of UPS, cooling systems, IT enclosures, switchgears/panel boards, standby generator, fire system and lighting systems. TCO also includes the management and security costs. TCO is calculated for data centre having the following characteristics: Location of data center: India, Asia, Data center IT capacity: 1000 kW, Average power density: 4 kw/Rack and Redundancy levels: N

4. Results and Discussion

The cost of managing the smart grid data on the cloud having 1 data center is $202560 (Figure 2) which is $2430720 annually. The calculated data center costs using APC TCO calculator based on same parameters comes out to be $5973185 which is equal to $ 5.97 per watt (Figure 3). Also the cost of servers having similar configuration as used in cloud is $700000. So the total data center investment is $6673185. The recurring cost is $748218 which includes power distribution & bandwidth cost of $539273, management & security costs of $ 158945 and maintenance cost of $ 50000. Using Equation (2) the NPV calculated for the datacenter project is $1517939.37, which is also shown in Figure 4. Using Equation (4), the ROI is 22.74% in 7 years, which is low as rapid changes in technology and uncertainty about future capacity requirements effects the data center operations. Experts estimate during the average design life of 10 years, a data center undergoes major equipment changes 3 to 4 times [27]. Each change of equipment is accompanied with increased demand of power and increased capital investments. In our example, at the end of the 7 years it's estimated that most of infrastructure will become obsolete and needs updation. Moreover due to data security reasons the server and storage devices need to be scraped/write off carefully. The scrap value just covers all the removal and disposal expenditures. The results suggests that keeping in view the present grid setup, nature of smart grid applications, ROI on building datacenter and benefits of cloud computing; outsourcing data and applications on cloud is economically sound option rather than capital investments in building datacenter.

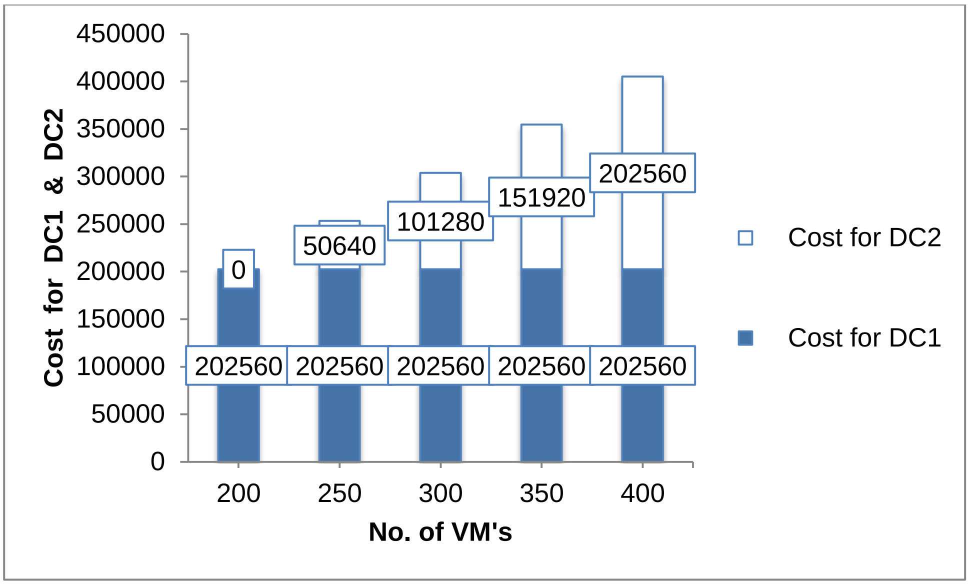

Figure 2. Number of VM's vs Cost

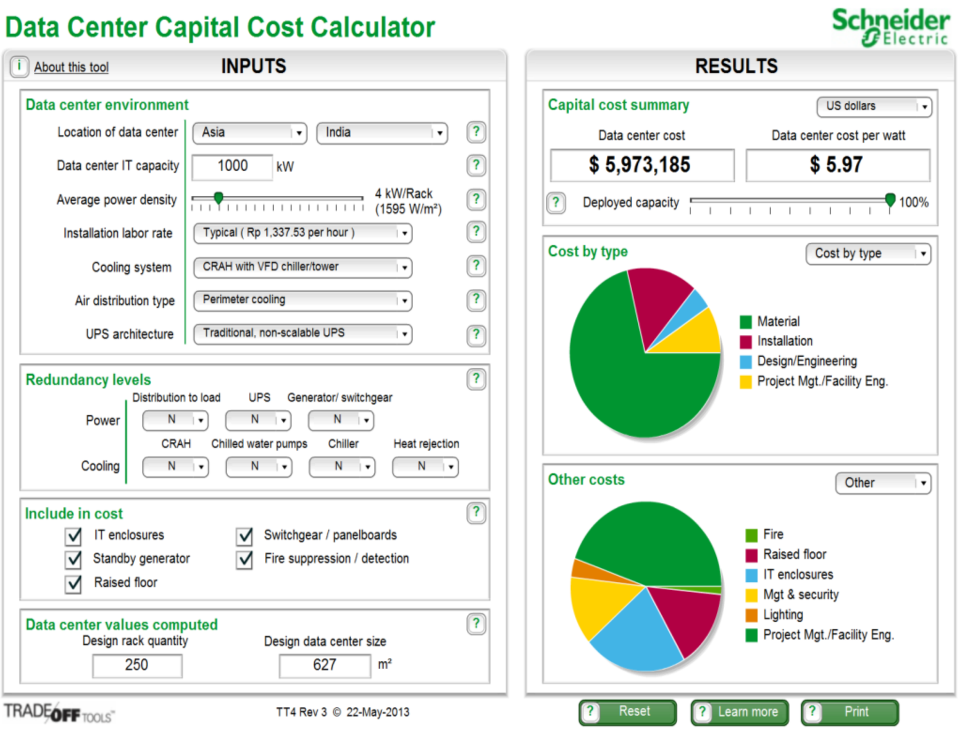

Figure 3. APC Total Cost of Ownership Calculator

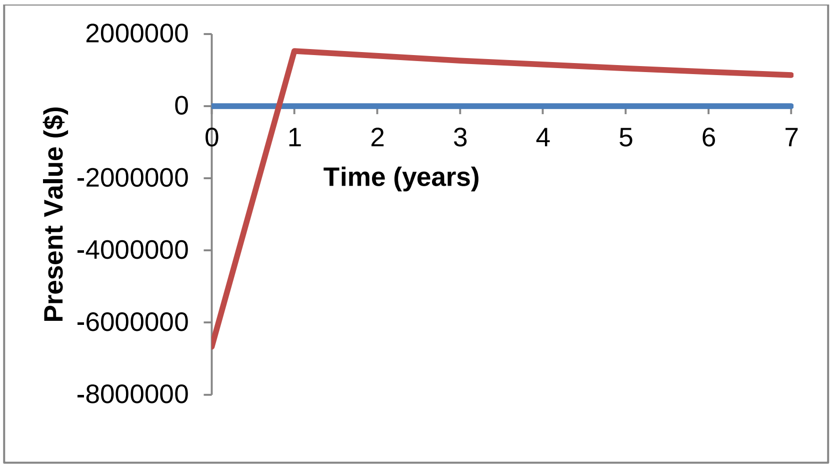

Figure 4. Net Present Value

5. Conclusion

The development of smart grid has led to the generation of monitoring data, so huge and complex that it is far beyond the scope of traditional storage and computational methods. Inadequate IT infrastructure at block level has posed challenge for accomplishing the smart grid vision for India. The unprecedented advantages: ubiquitous computing, on demand self-service, scalability, pay-per-use model has made cloud computing, a potential technology to be integrated with smart grid. The experiments are conducted on CloudSim to calculate the cost of processing and storage of smart grid data on cloud. The cost of managing the smart grid data on the cloud having 1 datacenter is $202560 which is $2430720 annually. The TCO of building the datacenter having equivalent computing infrastructure for smart grid data is $6673185. The ROI calculated using NPV formula for building data center is 22.74% in 7 years which is low suggesting that outsourcing the smart grid applications and data on to the cloud is economical than investing huge capital in building datacenter. This work will help the developing countries particularly India to make policies regarding the designing of cloud for smart grid. Full realization of smart grid cloud will ensure the maximum optimization of energy, transmission and distribution automation, reduction in losses, minimizing theft and demand-response through efficient storing and processing of smart grid data. Though cloud computing relieves the burden of upfront cost and maintenance cost of the data centers, it also relinquishes the owner's control on data. Outsourcing the data brings confidentiality, integrity, availability, accountability and privacy issues that may be exploited by attackers. Designing defense strategies, intrusion detection systems (IDS) and intrusion prevention systems (IPS) for smart grid cloud will be the future research direction in the areas of smart grid and cloud computing.

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