# *Enabling Energy Efficient Computing in the Presence of Intermittent Power Supply*

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# *Approval*

It is certified that the contents and form of the thesis entitled "**Enabling Energy Efficient Computing in Presence of Intermittent Power Supply**" submitted by **Ms. Rabia Akbar** have been found satisfactory for the requirement of the degree.

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***I dedicate this effort to my Parents and teachers for their consistent support and help right through my coursework and research phase***

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# ABSTRACT

Developing countries often have access to limited energy resources. This makes it crucial to utilize available energy resources as efficiently as possible. The limited energy resources also result in frequent and sometimes prolonged power cuts, during which enterprises rely on backup power sources such as uninterrupted power supplies (UPS) and electric generators. Building on the recently published work on Anyware [8], we propose Anyware-DC: an architecture that helps to reduce energy utilization in such environments, both when power is available and during power cuts. At the same time, it ensures no perceptible difference in user experience and no data loss due to power cuts. Anyware reduces energy usage by providing office users laptops instead of desktops, while maintaining performance levels through a centralized compute cluster. Our basic insight is that in the presence of power cuts, only the routers and the central cluster needs to be provided power; the laptops can continue to run on their own batteries. This reduces the load on the UPS allowing it to supply power for longer, thus saving generator fuel costs. Our simulation results show that over a period of 24 hours, this architecture reduces energy usage by up to 75% compared to one not using Anyware, and by up to 20% compared to one using basic Anyware.

# CHAPTER 1: INTRODUCTION

## 1.1. Background:

In today's fast paced and intelligent knowledge based society information and communication technology act as the core. The ever increasing innovation in technology has paved ways to a lot of different opportunities and has been adapted at tremendous speed all over the world, resulting in increased use of ICT in recent years. However this unprecedented growth has introduced some challenges as well (innovation comes with a price): the ever increasing overall energy consumption of the ICT systems.

The Climate Group estimated that ICT consumed up to 7% (168 GW) of global power consumption in 2008 and this number is expected to double by 2020 to 433 GW or more than 14.5% of global power consumption [1]. As ICT usage becomes more involved in our daily lives, this number will keep on increasing with the advent of newer technologies in the IT world. The escalation of portable systems such as laptops and smartphones, the increasing deployment of data centers, and the need for continuous power supply to ICT systems acts as some of the main reasons in rise of energy consumption in ICT. This leads to the need for energy efficient systems and adoption and implementation of better energy management strategies, making energy efficiency of ICT systems clearly a major R&D challenge.

A lot of work has been done on estimating and enabling energy efficiency in data centers but less focus has been given to computing enterprises which have the same share of energy consumption as other ICT departments. One of the reasons behind this is the diverse nature of an ICT enterprise which consists of variety of computing infrastructure, varying workloads, users and administration. The question to be answered here is where the energy is going, either the energy is used productively or the enterprise is paying for net losses. Research has been done in the past covering thin-client computing [2], dynamic VM migration [3] [4], network proxies [5] [6], and even network port deactivation [7] whereas enterprise computing has got significantly less attention in R&D field.

Today almost all industries are using machines which directly or indirectly require large amount of power. Green computing, also known as green IT, is one of the largest growing trends in business nowadays. The efficient use of resources in computing while maintaining performance is known as Green Computing. The main issues that green computing deals with are energy efficiency and promotion of environmental friendly computing. The main objective of implementing a green computing strategy in an enterprise is to minimize energy consumption of ICT, thus lowering its utility bills as well as lower its carbon footprint.

Data centers are the primary focus of green computing by implementing techniques such as storage consolidation and virtualization. As compared to the various studies dedicated to data centers, enterprise computing is given much less attention, although there has been a rapid growth in computerization of business processes and applications. This computerization of enterprises is resulting in higher energy consumption by enterprise computing.

## 1.2. Problem Statement:

For a country's economy and socioeconomic development, energy is considered as one of the vital organs, because energy is pivotal to keep industries operative and productive. With the increase in industries along with continued population growth in developing countries, the demand for energy is always on the rise, thereby making the supply and demand gap larger than before and resulting in energy crises.

The ever common energy crises in developing countries make the need to practice and apply energy efficient strategies and techniques more essential in these countries. Pakistan's energy infrastructure is extremely underdeveloped and poorly managed. Presently Pakistan is facing a gravely persistent energy crisis, which not only affects the routine life of people but is also restricting the industrial growth and hindering the country socio-economic development. In spite of the growing energy demand due to economic growth in recent years, attempts to overcome this crisis have not been very successful. The situation is getting worse with increasing demand, transmission losses, outdated infrastructure and lack of attention towards installing more energy production units. As a consequence we face long and frequent power outages, resulting in slowing down the economy's growth.

The limited access and availability of natural resources in developing countries makes it crucial to utilize the available resources as efficiently as possible. The lack of energy also results in regular and occasionally prolonged power outage periods, forcing enterprises to rely on costly backup sources. With this scenario in mind, this thesis focuses on the energy consumption of computing enterprises and asks the question: "How can we reduce the energy consumption of computing enterprises while maintaining the quality of the user experience and simultaneously supporting intermittent power supply?"

## 1.3. Thesis Objective:

This research proposes Anyware-DC: an architecture, built on the recently published work on Anyware [8], that helps to reduce energy utilization in such environments, both when power is available and during power cuts. At the same time, it ensures no perceptible difference in user experience and no data loss due to power cuts. Anyware reduces energy usage by providing office users laptops instead of desktops, while maintaining performance levels through a centralized computer cluster. For our architecture, in the presence of power outages, only the routers and the central cluster needs to be provided with continuous power supply by connecting a UPS, assuming the laptops can continue running on their own batteries before switching to a generator. This allows the UPS to supply power for a longer period, thus saving generator fuel and external energy consumption.

The purpose of our study is to reduce energy utilization both when power is available and when power cuts are in effect, while ensuring no perceptible difference in user experience. By building a simulator we analyze the performance of Anyware-DC in the Presence of intermittent power supplies. Our results show that enterprises in developing countries can use this architecture to ensure efficient use of their energy resources, help to reduce their energy consumption and save energy costs.

# CHAPTER: 2

## 2.1. LITERATURE REVIEW

The chapter gives a preview of recent work done in green computing to implement energy efficient solutions in enterprise computing and elsewhere. The increasing use of energy and the heavy bills paid by data centers, enterprises and households has made the importance of energy efficiency clear in these different domains.

A substantial amount of research has been done for data centers, as the relatively homogeneous computing platform makes them a favorable target for more energy efficient designs. Effective storage strategies, parallel computing, virtualization and migration and network power optimizers are examples of data centers research. According to [9], enterprise computing more or less consumes the same amount of energy as data centers, but has got less attention in the field of green computing.

The chapter presents a brief review of literature related to green computing solutions on how to save energy and energy efficient computing.

### 2.1.1. Energy-Measurement:

The traditional method of measuring the energy usage of a building or enterprise is by checking the monthly electricity bill or by checking the unit readings on a smart meter. The introduction of power reading via smart meters allows users to check their energy consumption in real time. The meters shows numbers for overall consumption of the building, instead of providing more granularity by specifying which component is using how much energy or in other words where is the energy going in the building.

To know how much energy is consumed by the computing systems in an enterprise it is not possible to rely on traditional meter reading. Different methods have been applied to capture the power consumption of computing systems. One study measured the power of each component of a computer, and then designed a model to estimate the power of a whole computer. More detailed studies take into account the applications, CPU usage or the workload on a system while measuring the power consumption hence producing more accurate models. In a setup like data centers, where the components are mostly homogenous a single model can be produced for a small set of the components and using extrapolation, the whole setup can be estimated. With the heterogeneous nature of a computing enterprise such an approach won't be possible, so it is important to measure each component individually due to the variety of hardware involved. Plug level power meters [8] provide a solution for these scenarios, where a meter is attached to the piece of hardware to be monitored and the power plug, taking instantaneous measurements. The difference between these power meters is the method of data storage used, from simply displaying the readings on the meter screen to automatically recording the readings in a memory on the meter and then uploading and saving the data by connecting the meter to user's computer.

The most advanced are Ethernet based meters, which requires access to network ports and send data in real time for long term continuous monitoring via help of some cables. A step further, there are wireless meters, which performs the same job but the real time recording of data on some device is done via wireless connection. These meters are used to measure the data for a set of systems and then generalize it for the whole class of such systems. This provides a rough estimate of energy consumption, but the limited number of systems measured might lead to inaccuracy in results. Another important aspect is the duration on which the data is collected: small durations are not ideal for accurate results. Mostly manufacturers provide a guide of the computing systems with the average power draw of each component, which might not be representative of real world power patterns. Some recent studies [10] [11] have deployed an extensive net of power meters in an office setup, which provide a more accurate power dataset.

## 2.1.2. Green Computing:

Since CPUs are the biggest consumer of power [12] in computing, they were one of the obvious choices for energy efficient and low power studies. In the past, efforts have been made to change the behavior of individuals towards the usage of ICT systems, but quantitative studies show that using systems efficiently saves more cost and energy rather than reducing their utilization [13]. The power consumption of a desktop lies roughly between 80 and 200 Watts, remaining continuously powered on for most of the time even if in idle state hence, wasting a lot of energy. A big problem is that these designs are not energy proportional in design i.e. the power consumed per unit of CPU utilization. This means that idle systems do not consume proportionally less energy: their power consumption is still substantial.

To overcome this, recent work has been done in maximizing the time for putting systems into low energy states i.e. sleep or standby states instead of the idle PC scenario. Another approach can be consolidation; making multiple users' machines run on a single shared server.

From here onward a discussion of existing green computing solutions and techniques and distributed systems is presented:

### 2.1.2.1. Sleep Systems:

Desktops consume a large amount of power when they are on, and this amount increases with greater CPU utilization. On the other even though when the system is idle it still requires substantial amount of power therefore wasting a lot of energy. Green computing has proposed solutions for dealing with the energy wastage of idle computers with sleep approaches. The goal is when the PC is in idle state instead of turning them off the PCs are put in sleep state.

Being in sleep state the PC draws around 5W as compared to 50 W when the PC is idle [14]. This is the same amount of power as a turned off PC, hence saving a lot of energy compared to being in idle state. Another positive to the sleep state approach is that whenever the user is back and active again, he/ she may start their task exactly from where they have left.

Although it is very much possible to turn off or put the PC in a standby/ sleep mode when a user is done with it, but research shows that enabling sleep mode manually is not practiced [15]. A survey conducted shows that in an office building at night only 4% of the desktops are in sleep mode [16]. The other option might be to automatically putting PC's to sleep via scheduling when they become idle. One of the drawbacks of the automatic approach is that IT staffs often disable this feature to make backup and maintenance easier [17]. Even if these practices are enabled the main drawback is that as soon as the PC is put into sleep state, the machine loses its network presence. This becomes undesirable when a user is running some application that might require continuous network presence, some background scheduled tasks by to be run during idle times and the need for remote access. To cope with this issue two approaches have been proposed, sleep proxies and virtual machine migration, which allow a PC to maintain its network connectivity even in the sleep state.

### 2.1.2.2. Sleep Proxies:

Sleep proxies or network proxies are techniques that solve the issue of always on for network presence. The proxy keeps the network connection on and responds on behalf of its sleeping host to incoming network packets. It needs to be always-on and on the same LAN network as its host. Early attempts of simple proxy approaches such as Wake on Packet (WOP) /Magic Packet would wake up a sleeping PC whenever there would be some network activity, and once the packet was served, the computer would go back into its sleep mode. The main concern in this approach was whether the host was able to stay in sleep mode for enough time. The performance of this approach will depend on the sleep time of the computer which in turn would depend on the inter packet gap. One study [6] shows that the sleep time for a computer with WOP enabled is very little and is comparable to the computer being in idle state. Hence WOP approach does not save much energy leading to solutions that require proxying idle-time traffic.

One such early approach is Somniloquy [5] which uses a USB based network interface. This approach keeps the network connection alive even when the computer is sleeping, by using a secondary processor interface. When the actual host goes into sleep mode, the Somnilouqy daemon activates the secondary processor which has a smaller memory as compared to the large hard disk space of the primary PC, to control the network requests. As soon as the actual host goes into sleep the network state is transformed from the primary processor to the secondary processor. This state transfer includes all network information and additional information such as when to wake up the host and study the incoming traffic and the required action for it. The proxy software on the machine responds to most of the incoming packets on behalf of the sleeping host whereas for more complicated jobs it triggers a wake-up call to the host processor. The paper shows that this architecture gets energy savings up to 65%.

Despite these savings the main drawback of this approach is the additional hardware, the application dependent stubs and the user disruption caused when the host is becoming active again.

Another software proxy approach [sleepless in Seattle] that used a simple reaction policy for the incoming networked requests was implemented in an enterprise setting on 50 active users for a period of 6 months. That study showed that the system allowed the systems to sleep for 50% of the time but showed only 20% of savings. This study as compared to [Somnilouqy] was implemented on actual users instead of test users and the main reason for the lower saving was that IT servers interrupted the sleep mode and hence resulted in lower sleep time.

#### 2.1.2.3. Virtual Machine migration:

The sleep proxy solutions are a good answer for the always on network presence and preserving the user work environment but the main challenge is changes required for individual applications and the OS itself. A different approach called virtual machine migration puts the idle PC to sleep while encapsulating its whole environment, instead of just the individual application, into a virtual machine and migrates it to a central server.

This migrated VM keeps the network connectivity alive for the sleeping PC. The advantage of migrating an idle PC to a central server is that while the PC sleeps, it consumes, while a single server can be shared by a number of sleeping PC's VMs, hence saving energy.

To save desktop energy by virtualization, a sleep server architecture called LiteGreen [4] was presented. The system virtualizes the user environment as a VM and then migrates it between the host's desktop machine and the virtual server. Each server and desktop runs a hypervisor; the hypervisors host a VM which is migrated to the server during sleep periods. All elements are connected via high speed LAN. The migration decision depends on whether the physical machine is idle or active. This migration lets the physical machine go into sleep state when being idle, while still maintaining the network connectivity and keeping the user environment always on. This operation allows LiteGreen to save energy even when the PC goes into small intervals of sleep. The overall implementation of the system on 120 desktops showed energy savings around 75% as compared to other solutions.

An extension to LiteGreen virtualization approach is energy-oriented partial desktop migration. This approach proposes to achieve energy proportionality while implementing partial VM migration as compared to full VM migration of LiteGreen architecture. The partial VM is migrated onto a server as soon as the physical computer becomes idle, the advantage of partial migration of VM is that due to low memory and disk space functionality it will make possible to accommodate more VM's on single server hence increasing the chances for saving energy and utilizing smaller idle time as well. The average savings of this approach are around 50%. Even with improved VM migration techniques, however, the problem of user disruption due to migration between the physical machine and the virtualized one still persists.

#### 2.1.2.4. Shortcomings:

The goal of the above approaches was to provide an always on network connectivity which allows remote access and continued functionality to those applications that require full time network connectivity. Although these approaches solved the problem of older sleep techniques such as manual or automatic sleep mechanism and WOP, they did not show any significant improvement in energy savings. Other challenges were the wakeup latency, use of extra hardware and the changes required to implement these approaches

Most of the works above utilized the idle period of a desktop and gained efficiency in those time periods. None of the studies have taken into account how to efficiently utilize PC even when it is active but not doing some heavy work such as reading a PDF or a blog etc. on system. Therefore there is a need for approaches in which virtualization must be in action not only when the PC is in a low power state but also when the active PC is lightly used. This is where the thin client computing concept is introduced.

### 2.1.3. Thin Clients:

With the current advancement in green IT, the deployment of desktop PC's in large quantity in an enterprise is becoming a challenging question. Other hindrances in making computing sustainable are the difficulty of managing desktops, and the frequent upgradation required of hardware, software and OS's, not applying power-saving mechanisms and the huge bandwidth required to serve the large fleet of PC's. To deal with this shortcoming, some approaches suggest the use of thin clients instead of Desktop PC's. In this mechanism a thin client device replaces the heavy traditional PC by running all applications and handling most of the I/O at a remote server level while being attached to the client device via network. [18]

The main aim of thin clients is to provide access and share a number of expensive resources on a shared server by the clients connected to the shared central server. Other benefits of thin client include reduced software and hardware costs, centralized management and energy efficiency. Desktop virtualization has added up to the positive experience of thin client users by providing them an experience of a full PC environment instead of just a graphical interface.

The advance in thin client computing is increasing drastically with solutions such as desktop virtualization [19] , to a point that a user no more notices much difference between a thin client and a heavy PC. In architectures like [19], the actual machine is always on the server, while the client device only displays it. Due to the low power of thin device, less energy is consumed and more users get a chance to share a single server. Studies [9] shows that a thin client uses between 8-15 Watts of power as compared to traditional fat desktops with an average power rating of 150Watts, hence resulting in saving large amount of energy

A similar kind of approach such as thin client is the remote desktop software [20] . In this the user's desktop environment is run remotely on a remote server or PC while being displayed on a separate client device. Examples of such architecture include Apple Remote Desktop [54] and NX Technology [55].

With all these advantages to a thin client approach, the main drawback of these light weight clients is the compromise made on the user experience, due to absolute remote execution of the tasks. When a user is using a graphical application such as adobe Photoshop or playing a video, such application does not perform well on thin clients due to the remote executions. To overcome this shortcoming, some solutions like [21] are proposed in which the server sends pixels instead of display command to the client.  Another such approach THINC [22] uses virtual display architecture. Other drawbacks of a thin client approach are the latency, no backup for applications and limitations in connecting peripheral devices directly to the client device.

## 2.1.4. Distributed Computing:

In distributed computing, a number of desktops are connected to each other via a network which is capable of participating in a single task, these are known as distributed systems. These inter-connected nodes have their local memory and communicate with each other via message passing. Early examples includes client-server, Peer to Peer a computing or task performed on any such system is called distributed Computing. With the advancement of faster and cheaper networks distributed computing is becoming increasingly common. The main benefits provided by such system are resource sharing, scalability, fault tolerance, better performance and increased computing speed. Some of the disadvantages of these systems as compared to a centralized system are Latency, Heterogeneity, Memory Issues, Security and Synchronization issues.

### 2.1.4.1. Offloading:

The transfer of heavy computing tasks to a remote platform such as a server, cloud or powerful desktop machine is known as computational offloading. Recently offloading has been explored in mobile systems, due to their resource limitations such as smaller memory, battery life, and processor speed and network bandwidth. In computation offloading for mobile systems, heavy computations are sent to a more powerful server and then the results are received back on the mobile device.

Developments in virtualization, bandwidths and cloud technologies have made computational offloading practices more practical. A number of studies have proposed solutions for saving energy via computation offloading. Studies shows that the saving depends on parameters such as the load to be offloaded, the type of load, bandwidth, storage capacity and server speed [23]. The task of offloading can be performed on different levels from tasks [24], applications [25] or on VM's [26].  The enhancement of wireless network connectivity in mobile system has led to enablers like mobile agents, which initiated the concept of relocating computations from mobile devices. Several studies including Kotz et-al [27], Wong et-al [28], joseph et-al [29] tried to achieve platform independence and to migrate computation for mobile devices. A number of algorithms have been suggested and designed [23] to improve performance of mobile devices and to save energy [30], [31]. Cloud computing has also been an active participant in computation offloading concept, e.g. [26] uses the idea of cloud computing to allow offloading.

All of these proposed solutions still needed a number of improvements to enable efficient offloading, user transparency, security, user privacy and mobility were some of the major shortcoming. While solutions have been proposed for some of the above mentioned shortcomings such as inter operate ability [26] , [32], mobility and fault-tolerance [33] [34] , privacy and security [35] [36], these issues still continue to be active areas of research and development.

Recent architectures like MAUI and clone computing suggest offloading of computations from phone to a cloud. These solutions address the issue of code offloading by migrating pieces of code between mobile devices and server but the solutions are not practical enough for enterprise computing. Google Chrome book proposes a framework which resembles the idea of thin clients i.e. by migrating the whole computation onto the cloud, while no work is being done on the local machine.

Despite the proposed solutions that improved the computational speed of the mobile devices, the issue of battery life, security issues on cloud and the practical implementation of these solutions for computing environments still remains a challenge.

### 2.1.5. Summary

There is noticeable development in the field of Green IT and energy efficiency, but still the focus is only limited to a specific characteristic of Computing Systems. Many green computing solutions provide a solution to lower the use of energy but by putting the PC's to sleep only when the systems are idle. However, research has shown that even when systems are active most of the time they are on low utilization mode doing some light weight task. Sleep systems ignore the idea of efficient use of the systems and saving the energy wastage when they are active while performing some light weight computation. Another drawback of sleep systems is the latency in making the active user platform available again. Thin clients address this issue by sharing the resources over some remote server, but the complete dependence and computation of tasks remotely, compromises the performance of some tasks which might be performed better by utilizing local resources. Another way to tackle the problem of utilization of shared resources is remote execution. With improved security and faster and larger bandwidths it is very much possible to adopt this solution to utilize different combination of local and remote resources.

## 2.1.6. Anyware:

Anyware [8] is a hybrid design for enterprise computing that provides a solution to reduce the energy consumptions without any loss of performance or putting devices to sleep unlike past solutions. We discuss this architecture in more detail in chapter 3. Anyware builds their architecture by sharing the idea of remote execution but with shared server and lower end computers. The architecture is built on top of existing solutions [37], which enables a program to be remotely executed on a remote machine by using NFS and X-forwarding systems. The goals of Anyware architecture are to support heavier workloads and save energy without compromising on user performance. On the other hand, to avoid the need for virtual machines on the user's local machine or involvement from developers, Anyware migrates complete applications instead of portions of code. Anyware achieves a net energy saving through sharing of resources on the server, unlike mobile device migration systems which do not take server energy into account.

### 2.1.6.1. Overview:

The idea behind replacing desktops with laptops is that on the average, there is very low utilization of PCs. These light weight tasks can be handled by light weight systems such as laptops which only consume average 24 W as compared to 80-200 W by a desktop. Building on this assumption, Anyware proposes to replace the fat desktops in an enterprise with light weight laptops which are connected to a central cluster via LAN. Past studies of thin clients presented the same idea with the drawback that offloading tasks completely to a remote cluster might result in underutilization of local machine resources. Studies confirm that some tasks are better performed on local host instead on a remote server. Anyware being a hybrid architecture utilizes the idea of thin clients without sacrificing performance by running the tasks which are performed better locally on local host while offloading the other tasks simultaneously to a remote server without the user experiencing that any of his task is being run remotely. To run the applications remotely, assigning and finding server for them the client does not have to make any configurations except for running a single script only once on his machine. Anyware remote servers use Avahi Zeroconf to advertise themselves. The software executes an Avahi query and then the advertisement is parsed to get the server IP address and port. The client then uses them to establish a socket connection and download the rest of the setup scripts from the server.

Leaving the job of deciding whether a task will perform better locally or remotely on a user would produce difficulties for a novice user. For that reason experimentation was done on 5 users for 25 applications by randomly running them locally and remotely. The I/O intensive tasks run better locally as compared to remotely their experience. Based on this experiment, a logistic regression model is implemented which chooses the running of the job by either assigning the task a 0 for local or 1 for remote value. Based on these results, the Anyware daemon makes the decision on whether to run locally or remotely.

Due to the low disk availability and slower processing power of a laptop to a desktop, this might seems like a bottleneck in Anyware case. To test the performance of Anyware to a desktop an experiment was done by running 3 different workloads on a laptop having Anyware, a thin clients and a desktop all connected to same VLAN. The results show that with lower storage available on the laptops, I/O intensive tasks perform better on a desktop. To overcome this deficiency Anyware designers replaces magnetic disks with solid state disks (SSD), which results in equivalent and in some cases exceeded performance from a desktop.

Tasks that require extensive amount of data transfer over the network or which require some dedicated hardware performs better locally e.g. google earth and video playback, which validates the need of a hybrid architecture which unlike thin clients utilizes local resources when needed.

The authors also test server consolidation i.e., when multiple users will share the server, will it have any effect on user experience, by analyzing the memory, CPU and network traffic by some workloads and testing it for G-Numeric, Gimp and text editor applications. No noticeable difference is experienced for the three tasks on memory side, but by running the workload for CPU, the text editing task is not affected, but G-Numeric and specially GIMP which is a CPU intensive task are affected. For network traffic there is no noticeable difference for GIMP and a slight difference for spreadsheet task but the text edit task is most affected due to opening the files etc. This experiments gives an insight of how a server will be affected if it is overloaded hence when a server should stop accepting more tasks.

For a server shared by 25 users, the Anyware setup consumes around 20 watts for a single user i.e. an 80% reduction as compared to desktop, whereas for 100% utilization or an active user the Anyware setup draws around 35 watts per user which comes out to 60% efficiency.

# CHAPTER: 3 METHODOLOGY & EQUIPMENT:

## 3.1. Anyware-DC:

Anyware claims that replacing Desktops with laptops in a computing enterprise can result in 80% of power consumption, where office PC's spend most of their time in very low utilization. As per the study two-thirds of office CPUs are used less than 10% almost 75% of time. Hence for such light weight tasks a laptop will be an ideal candidate instead of a heavy desktop, while offloading the heavy tasks to a centralized cluster in order to get power savings and lower the cost. Anyware shows a 75% increase in the efficiency, but the prototype does so for a scenario where the power supply is continuous. The Anyware architecture requires 24/7 supply of power as the central server and client are connected via LAN. Even a small fraction of power loss can result in large data loss and failure of important tasks.

Developing countries often have access to limited energy resources. This makes it crucial to utilize available energy resources as efficiently as possible. The limited energy resources also result in frequent and sometimes prolonged power cuts, during which enterprises rely on backup power sources such as an uninterrupted power supplies (UPS) or/and an electric generators. As Anyware does not make any extra attempt to implement the architecture in such environments, implementation of Anyware architecture in these environment will result in loss of large important data, user dissatisfaction, latencies overall Anyware won't be a successful architecture for developing countries. To cater this need we propose our architecture Anyware-DC (developing countries).

Building on the recently published work on Anyware [8], we propose Anyware-DC: an architecture that helps to reduce energy utilization in such environments, both when power is available and during power cuts. At the same time, it ensures no perceptible difference in user experience and no data loss due to power cuts. Anyware reduces energy usage by providing office users laptops instead of desktops, while maintaining performance levels through a centralized computer cluster. Our basic insight is that in the presence of power cuts, only the routers and the central cluster needs to be provided power; the laptops can continue to run on their own batteries. This reduces the load on the UPS allowing it to supply power for longer, thus saving generator fuel costs. Our simulation results show that compared to pure Anyware, this architecture reduces energy usage by up to 20% over a period of 24 hours.

### 3.1.1. Overview:

Computing equipment has become one of the major energy sinks in corporate and academic buildings today [12]. While computers enable remarkable increases in productivity, their energy costs have continued to increase over the past several years. Developing countries, including Pakistan, can benefit greatly from the higher productivity that is possible through office automation using computers. However, developing countries often have limited energy resources. This makes it crucial to utilize the available energy resources as efficiently as possible. Furthermore, limited energy resources often also lead to frequent blackouts and sometimes prolonged power cuts, during which backup power sources such as uninterrupted power supplies (UPS) and electric generators have to be utilized to keep the computing equipment running.[ For other companies, such as Data Centers and financial services organizations, where any downtime impacts severely on company reputation and profits, any loss of power will have severe implications, therefore having a standby strategy is a paramount]

We propose a computing architecture for office buildings in developing countries to drastically reduce energy utilization both when power is available and when power cuts are in effect. At the same time, our architecture ensures no perceptible difference in user experience and no data loss due to power cuts or surges. The key idea, based on the Anyware research project [8] carried out at Stanford University, is that office users should be provided only laptops for their office work. However, to conduct more CPU-intensive operations, the laptops are connected to a small server cluster that can execute compute-heavy tasks transparently from the user. Since one server can handle the compute-intensive tasks of many laptops, the total energy utilization is greatly reduced.

We present Anyware for Developing Countries (Anyware-DC) fig (1) to support energy-efficient computing in the presence of frequent and possibly prolonged power cuts. We propose that by connecting the UPS only to the server cluster and the network equipment, we can avoid expending its stored energy on a whole host of computers spread throughout the office. The laptops can continue running on their own batteries without either UPS or main power supply. This could allow the UPS to continue running for a much longer period of time, thus increasing its battery life as well as reducing the need to switch to generators. For extremely long periods without power, we also propose a simple battery-monitoring application running on the laptops, so that the generator can be automatically switched on if the laptops start running out of power. If some laptops have significantly lower battery lives than others, we suggest external battery packs to keep them running or simply investing in newer laptops.

Our simulation results show that this architecture results in up to 80% reduction in energy consumption compared to a system not using Anyware, and a 33% reduction over a system using the basic version of Anyware.

The rest of this thesis proceeds as follows. The next section describes our proposed architecture in more detail. Section 3 presents detailed evaluation of the equipment choices made for Anyware-Dc. Finally, chapter 4 presents a simulation-based evaluation of the architecture including potential energy savings and the factors that need to be in place for this architecture to be beneficial.

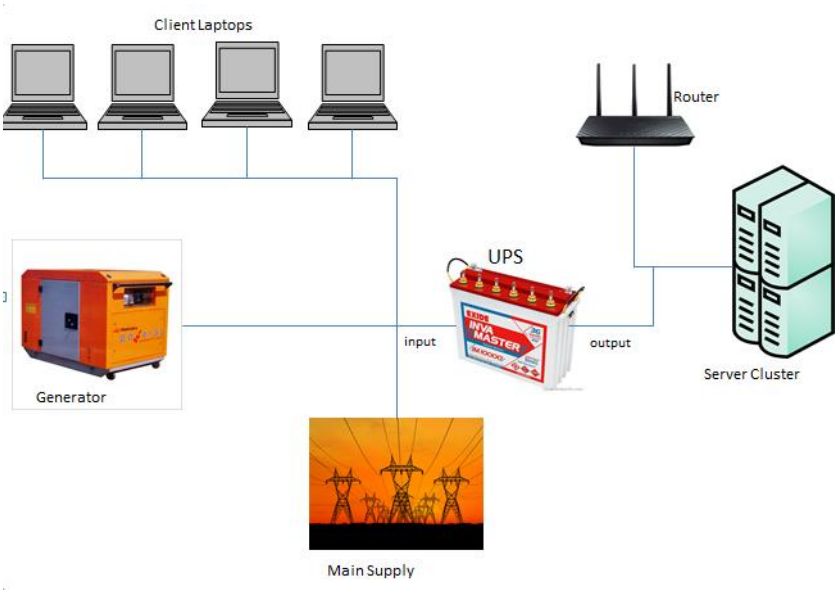


Figure 1

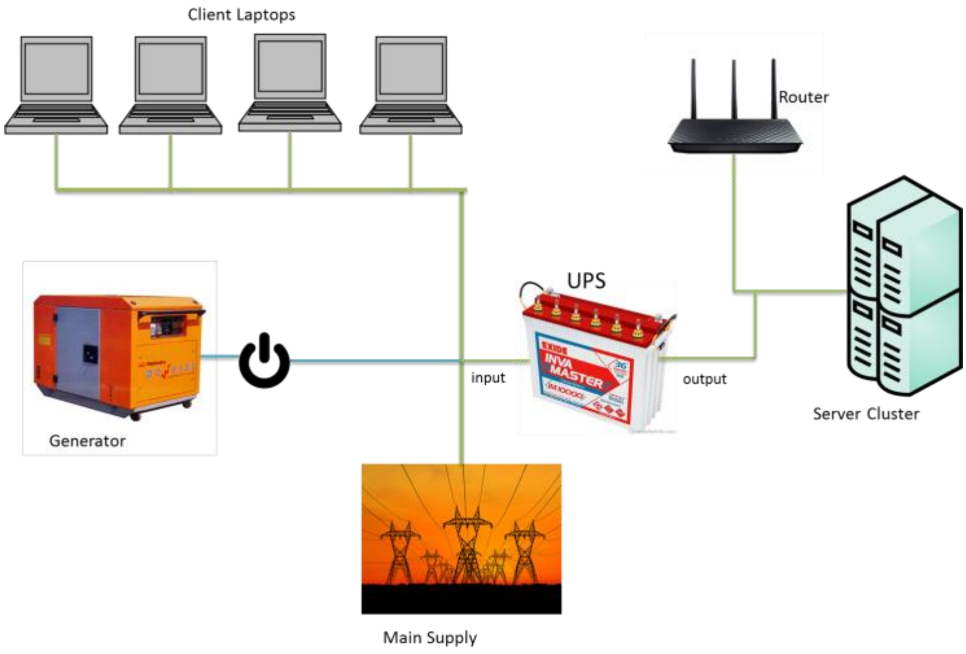


Figure 2

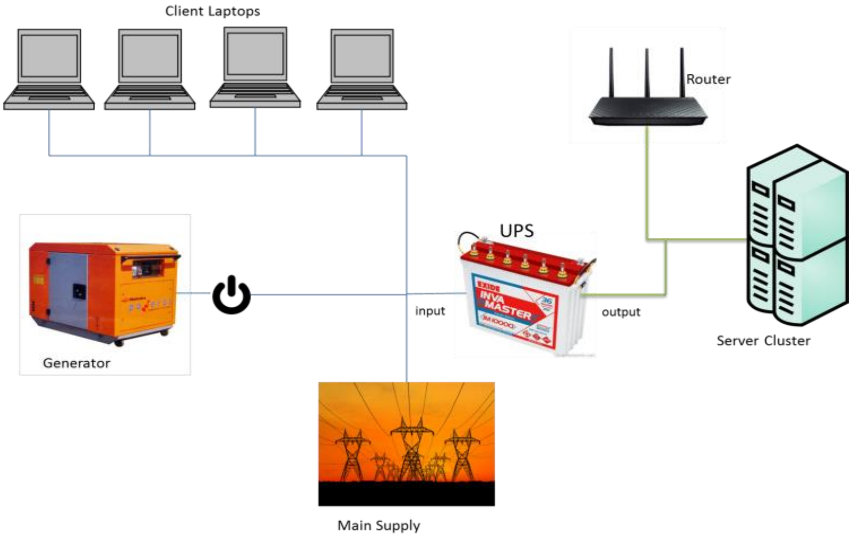


Figure 3

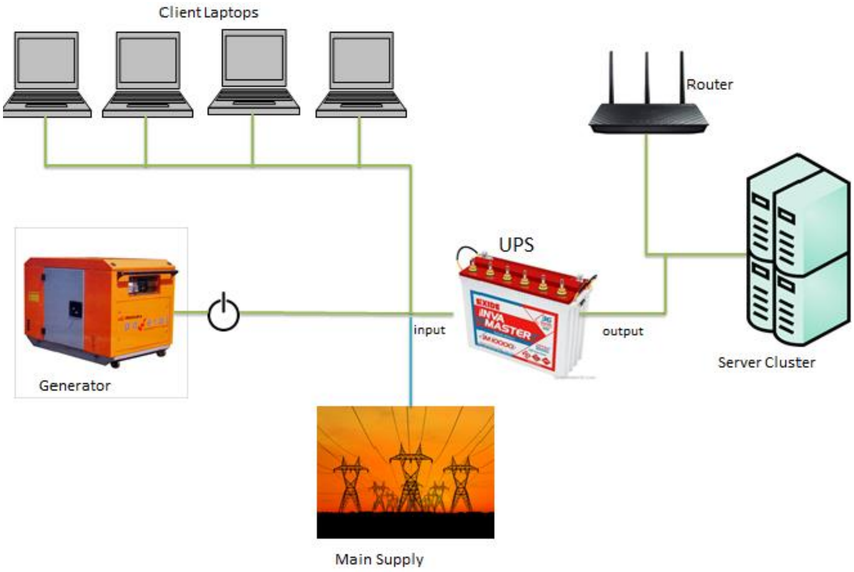


Figure 4

We propose Anyware-DC, an architecture that extends Anyware to deal with environments where power outages are common. The existing Anyware architecture is designed for environments where there is a constant, uninterrupted supply of power. As a result, it makes no extra attempt to conserve energy during periods of power loss.

Our proposed system leverages the fact that laptop batteries have their built-in power backup acting as power supply, to decrease energy consumption and provide backup during a blackout or power cut. Instead this power backup provided by the ups will be utilized to provide backup power supply to Anyware's central server cluster and to networking equipment such as routers and switches. Since the server cluster is small and the number of routers and switches is much less than the number of laptops, the energy consumption is greatly reduced. This allows the UPS to continue supplying power for a much longer period of time.

In normal conditions the main grid supplies power to the connected laptops, server cluster, switches and charges the UPS (Figure2). In case of power outage the UPS backups the center clusters while the laptops utilize their built in battery backup (Figure3). In case one of the laptops runs out of battery or the UPS reaches its threshold value a flag is raised and the generator switch connects to acting as the power backup source for the UPS and the Laptops, until main power returns (Figure 4). In this way the period during which the UPS runs the energy consumption is greatly reduced.

As the laptops utilizes their own backup and the ups only backups a small in case of our architecture, following benefits are gained:

- The batteries performs better and for a longer period of time
- Because of the longer backup provided by the UPS, the generator is utilized minimum.
- Because of smaller load, small batteries will be required for the UPS to back up the load for our architecture as compared to desktop and Anyware-ups architecture, the size of generator which will be backing up the whole architecture including the ups will be smaller.
- Because of the smaller size of generator our architecture will consume less fuel as compared to desktop and Anyware-ups architecture.
- Because of the smaller batteries of ups the power required for the ups during main supply will be less for our architecture compared to the desktop and Anyware-ups architecture.

In this way our architecture will make significant energy savings as compared to the desktop architecture and Anyware-Ups architecture.

### 3.1.2. Battery Monitoring:

For simulation purpose we assume the minimum backup of each laptop to be 3 hours. In situations where a laptop's backup might fall below the threshold level we have specified in our simulator script during the time when the ups is backing up the architecture, some kind of battering monitoring mechanism was required to raise a flag and shift the backup from the UPS to the generator in order to backup any dying battery of a laptop/s.

As our simulation script is run on Ubuntu, for the purpose of battery monitoring we will be utilizing the file systems directory in Ubuntu which stores the ACPI information of the system. /proc and /sys contain files used to check the status of battery in Ubuntu. Only a single command line /sys/class/power_supply/BAT0 will be required to run the file systems and check the battery status. For our simulation purpose we return the results of the command in percentage to a variable" state" "state = commands.getoutput("grep \"^charging state\" /proc/acpi/battery/BAT0/state | awk '{ print $3 }'")". The value of "state" is compared to the threshold variable and as soon as the values are equal below the threshold the Ups flag turns 0 and Generator flag turns 1. For the purpose we define this within a function and call the function periodically to check the battery status.

We simulate this scenario and present some numbers in Chap 4.

To select appropriate hardware and software for the purpose of our simulation, several considerations have been made:

- What are the critical business systems that need short-term power protection, and those that need a long-term alternative power source?
- What equipment needs to be protected by Gen?
- Which equipment requires UPS?
- What will be our Choice of backup supply? Primary and Secondary?
- What should be the Size of UPS batteries?
- What should be the Size of Generator?

The remainder of the chapter provides detail of the topics and concepts that will help us find answers to the above question, and to help us make the right choice to choose our equipment.

## 3.2. Laptop and their Batteries:

In the past desktops dominated the markets as compared to laptops but with the advancement of laptops with longer battery life and powerful processors, laptops are gradually pushing aside its counterparts due to its feasible price, mobility, better visuals and above all less energy consumption. Nowadays almost every individual owns a laptop due to its portability, single chord and almost similar processing to desktop. The main leverage that Anyware-Dc has over the traditional Anyware is to utilize the built-in backup energy of laptops stored in their batteries. In order to utilize it efficiently, the right choice of the laptop is one of the most important steps of our equipment selection. No matter how good specifications a laptop offers if it cannot provide the user with longer backup hour it will be considered useless. A laptop is a battery or AC powered portable and compact personal computer with the same functionalities and capabilities as a Desktop. With the advancement in the laptops the main focus of the laptop industry is the longevity of its backup battery. With a little additional price and a wise one time investment a large number of choices are present in the market, from Lenovo ThinkPad T450's providing 15 hours backup battery to the very affordable Acer Chromebook 15's 9 hour battery backup life. Keeping in view the market of Pakistan mostly Personal Laptops provide an average of 4-5 hours Backup.

## 3.3. UPS:

UPS called uninterruptable power supply is an electrical power source connected between power utility and load that provides emergency power to the load when the input power supply i.e. the main supply fails to do so

### 3.3.1. Working of UPS:

The UPS functions as a battery backup, i.e. it converts AC into DC and stores the charge or in other words charges when the main power is on and as soon as there is any kind of power disruption or shut offs it uses this stored energy to backup power supply to electronic devices by converting the stored DC into AC for devices usage. For this purpose a UPS consist of several components such as batteries, rectifier, inverters and switches, working together to make the functioning of a UPS possible.

Rectifier: the main job of rectifier is to do rectification i.e. converting Alternating current to Direct current into to use this direct current as source of power, as well as to provide battery charging voltage.

Inverter: An inverter works exactly opposite of a rectifier, i.e. converting the DC current into AC.

Battery: it is a storage device, consisting of series of cells which stores the chemical energy in it. When the batteries are on charge, the input energy is converted into chemical energy and stored in the battery, as there is a power outage the battery provides the energy to load. Batteries are an essential component of the UPS as the choice of batteries decides the output power/ backup time of the UPS.

Static Switch: the static switch automatically switches the control from inverter back to the main power supply or some other backup supply, in case of failure of an inverter, main supply becoming available , or in case of ups batteries running out of charge

The functioning of a UPS under Main power supply/ while charging and being used as a backup power supply in case of power outages or other interruptions is shown in Fig(5). In normal conditions, UPS is supplied with power via main power supply, the rectifier converts incoming AC into DC and store it into the battery while the switch is connecting the load to the main. In case of a power loss the switch shifts the load connection to inverter, and the inverter converts the stored DC charge back into AC to run the load. The switch controls when the load is connected to the main and when the battery and load are connected to the inverter.

When specifying UPS for our architecture the main aim should be to consider the requirement of the system and to protect the functioning and power of the systems that are critical to an organization, which must be kept running during any power loss period. Computing infrastructures like data centers and mainframes require large heavy duty hours UPS, the development in computing like WAN and LAN with lower power capacities have made it possible and easy for smaller UPS's to be utilized as backup sources. The 2nd consideration is to choose the right type of Ups for our architecture.

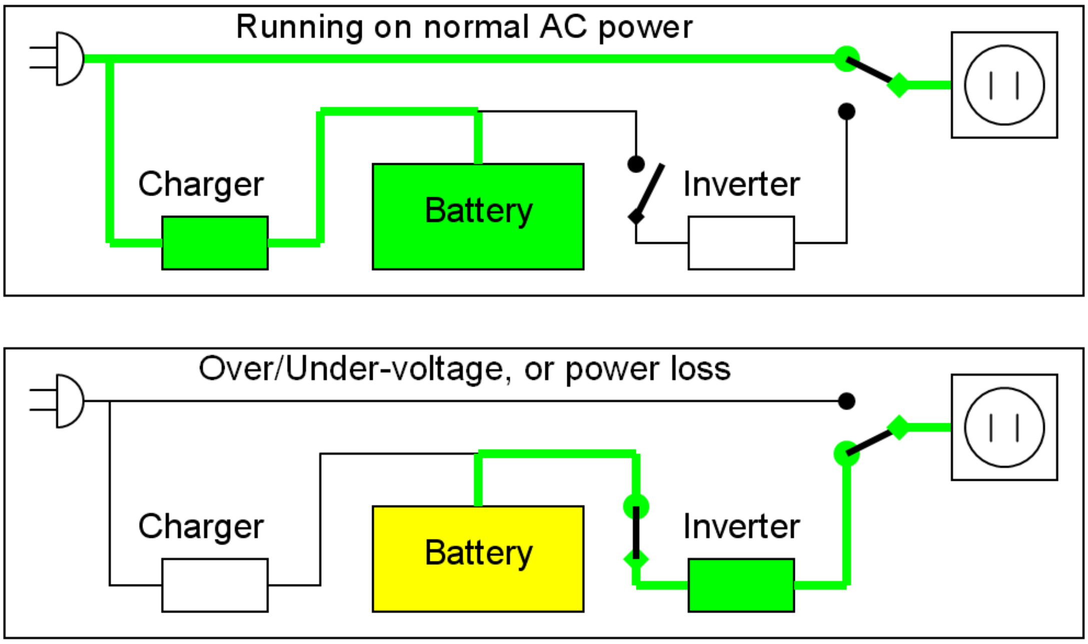


Figure 5 [38]

## 3.3.2. Types of UPS:

### 3.3.2.1. On-line UPS:

The main function of online UPS is to supply clean and regulated power to critical system even when the main supply power is available, in order to save the extremely critical systems from any kind of electrical irregularities such as power surges and spikes, frequency variations, main power outages and so on. These types of UPS are expensive and are of complex nature.

### 3.3.2.2. Off-line UPS:

These simpler and less expensive Ups are also known as stand-by Ups, which protects critical systems against power failures only. The functioning is of a basic up i.e. in presence of main the load is directly powered by the main while a DC line is supplied to batteries in order to get them charged. While in case of power outage the inverter powers the load by using the stored energy.

The other kinds of Ups not related to our research are Line interactive UPS and rotary UPS.

For our architecture we use offline ups, based on following assumptions:

LANs and WANs, made up of many smaller nodes with one or more file servers, may require much smaller, off-line UPS units, often with self-contained batteries. As a minimum, file servers and critical workstations should be protected by an off-line or line interactive UPS. The amount of battery back-up (runtime) is usually limited to that required for an orderly shutdown of the network.

Offline-UPS units are a better choice for architectures having LANs and WAN's which limited nodes and servers have connected to it and each other. As our system will consist of some servers that would require protection in case of power outages only, an off-line ups with a self-contained battery will be a better choice. [39] . The other reason for off-line ups is it is cheap as compared to its more complicated and expensive counterpart an online-ups, additionally acting only as power bridge between the main and the load in case of power outages as compared to running the load and charging continuously in case of on-line ups, the UPS runtime increases considerably and the power consumption is lower as well. The other leverage is the UPS runtime can be considerably shorter than if the UPS is operating alone, the UPS acting as a power bridge between mains power failure and the generator taking up the load.

The power Factor for off-line and on-line interactive ups is btw 0.5-0.7, whereas for on-line interactive its 0.8 generally [38]

## 3.4. GENERATOR:

Generator is another appliance that can be used as a backup power supply in case of emergency or routine power outages to prevent discontinuity of daily tasks. In this section we will briefly look at how generators function, their architecture, and their types and how a generator does operates as a secondary power providing source. After going through brief description of these we will be able to find answers to the selection of generator for our architecture.

### 3.4.1. Working of Generator

The basics behind this device functioning is, it converts mechanical energy into electrical energy. It does not create the electric power supplied to the devices, but just like how water pumps works it forces the movement of electric charges through a shaft in a magnetic field, by using the mechanical energy that is supplied to it. This flow of electric charges results in the production of electric supply.

Engine is responsible for the mechanical energy supplied to the generator. The larger the engine is the greater the output is. These engines' operates on different kind of fuels and now gases as well including, petrol, diesel, gasoline, biogas etc. the alternator is responsible for converting the mechanical energy supplied by the engine to be converted into electrical output. The alternator encapsulates a stator and rotor which are responsible for creating an electric charge by via metal wiring or a coil, and to produce a magnetic field. By relative movements these electric and magnetic fields produces electricity. The fuel tank is which determines the capacity to store the fuel supplied to the engine throughout the generator functioning. The larger the tank capacity the longer the generator runs. A voltage regulator is used to regulate the output voltage of the generator. There is a in-built cooling system in a generator in order to exhaust and cool down the heated areas of a generator due to continuous use. The lubricating system ensures durability and operations of moving parts of the generator's engine. Overall a mechanical force is supplied to the generator which moves some electric conductor such as a wired coil hence inducing electric charges. By doing so the flow of electric charges is made possible, as this creates a voltage difference between the two ends of the coil thus generating electric current. [40]

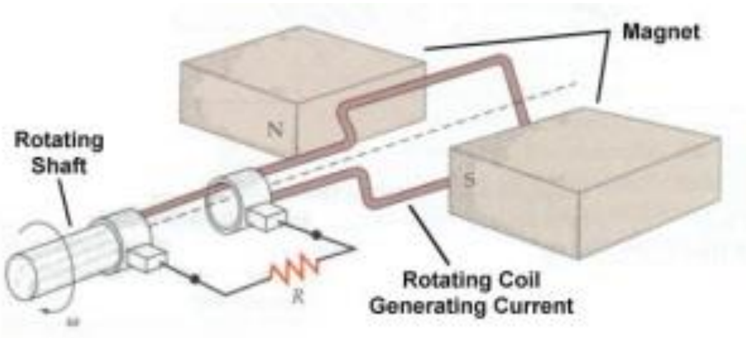


Figure 6[41]

To support IT systems in case of a power supply, a small standby generator will be a better choice as compared to large size installed generators. With advancement in generators a variety of generators are present in the industry which are less expensive, easily portable, and efficient and works well on 100% load. The most common choice of fuel for stand by generators is diesel. One of its positives is its easily availability, cost effectiveness and low flammability as compared to natural gas. One of the main disadvantage of natural gas as choice of fuel is, that it will require a larger tank and the availability of natural gas petrol is only considered for very small generators due to its tendency of fast degradation over time.

Anyware-DC will require backup for a small to medium load in power outages while keeping the cost and consumption of the fuel minimum but easily available. A small standby diesel generator will be the right choice for our design keeping in view the above advantages and disadvantages of types of generator and the fuel required.

## 3.5. Equipment Categorization:

In case of power outages the enterprise computing needs to determine what are the continuity and recovery needs of the organization and which critical systems require instant power protection  and which systems requires a long- term alternative power source. To answer these questions it would be beneficial to evaluate the systems that are involved in the organizations functioning. As different systems require different level of protection it will be beneficial to categorize them according to their criticality and functionality.  Following are the different type of systems:

Those systems which cannot withstand any kind of failure for more than 4 milliseconds, and must be kept functional as long as possible are called "critical" systems. These systems require UPS with heavy batteries for longer backup or in severe cases a combination of UPS and Generator both. The systems that just require a safe shut down instead of crashes and failures are known as "sensitive systems". They just need a UPS providing the systems enough time to save all the operations and data before shutting down safely.  "Essential" systems might be backed up by other power sources but the best choice would be a stand by generator.  The last category is the "Other" equipment's whose continuous functioning is not so essential in case of power failures, and their absence won't have any dire effect on the critical or essential equipment's or on overall organization. Based on the above types and criticality of different systems in an enterprise the equipment can be categorized in following categories.

•'Critical' systems require the Backup of both UPS and generator.

•'Sensitive' systems require only UPS Backup

•'Essential' systems require Generator as Backup Source

•'Other' systems can stay powered off during power cuts hence no Backup required

Table 1

| Equipment | Quantity | Consumption(/hr) |
|---|---|---|
| **Laptop** | 24 | 24W |
| **Server(per user)** | 1 | 11W |
| **Switch/Router** | 1 | 11W |
| **UPS** | 1 | |

Table 2

| Equipment | Category |
| --- | --- |
| Laptops | Essential |
| Servers | Critical |
| Switch/Router | Essential |
| UPS | Essential |

### 3.5.1. Equipment Protected by UPS

Table 3

| In case of Anyware-DC |
| --- |
| Equipment |
| Servers |
| Switch/Router |

Table 4

| In case of Anyware-UPS |
| --- |
| Equipment |
| Laptops |
| Servers |
| Switch/Routers |

### 3.5.2. Equipment Protected By Generator

Among the equipment that requires Generator as the Backup source UPS tops the list, as it is responsible to protect the critical systems in addition to the Laptops.

Table 5

| Anyware-DC |
| --- |
| **Equipment** |
| **UPS** |
| **Laptops** |
| **Servers** |
| **Switches** |

Table 6

| Anyware |
| --- |
| **Equipment** |
| **UPS** |
| **Laptops** |
| **Server** |
| **Switch/Routers** |

## 3.6. Choosing UPS as the primary Backup Source:

We choose UPS as the primary Backup Source for our critical systems due to its easy portability, noise free functioning, low maintenance and cost and automatic supply of backup without any latency in case of power outages . In case of prolonged power cut outs when the UPS battery surpasses its threshold level, we choose to switch to Generator as secondary Backup Source for our systems.

Although a generator provides a longer run-time as compared to UPS, it does so by adding additional cost, extra maintenance, noise, emission of dangerous gases and the latency in startup time. In order to achieve an extended output time from a UPS an investment should be made in buying powerful External Battery Packs for the UPS. UPS with external battery pack are much more reliable as compared to generators and require low maintenance. This kind of UPS when used with a combination of generator i.e. utilizing the generator backup until the generator kicks in, it provides an extra layer of protection and uptime. The maintenance costs of UPS is much lower as compared to that of a generator, the UPS batteries needs periodical checkup and are reusable while requiring a change after an average of 4-5 years. [41]

## 3.7. Ups Battery Size and Backup Time:

UPS charges promptly after discharge in order to prevent battery damage due to excessive self-discharge. For long life of the batteries the activation of the charges inside the batteries is essential, which takes place while UPS is discharging. So for long life batteries the batteries must be fully drained every two-three months [38]. A number of battery types are available in the market; the choice of battery depends upon the requirements of the system it is needed for. Rechargeable Alkaline, NiMH, Nli Cd, Li ion, Lead Acid. We will assume Lead Acid batteries for our UPS. The Lead Batteries have a greater output voltage, inexpensive as compared to other newer technologies and its recycling rate is 93%. The only problem is they are heavy and not easily portable and dangerous to handle due to presence of Acid. The lead batteries will be deep cycle type as they are designed to handle deep cycles i.e. continuous discharging and charging, and deep discharging of the batteries. Deep cycle batteries can be cycled down to 20% charge. [42]

## 3.8. Generator Sizing Strategy:

Generator is our secondary source of our power backup once UPS fails to supply required backup in times of prolonged or frequent power outages. The correct sizing of a generator is a daunting task and a crucial step in order to supply enough output to keep the systems safe from malfunctions and keep them running. The correct sizing of a generator is not as simple as one might at first suppose. Study shows that a generator with greater capacity then the apparent required capacity depending on the total load is a safe and wise option. After categorizing the equipment in section 3.5 the next step is to keep in mind the following consideration while calculating the size of a generator:

While sizing a generator we need to keep a check for any kind of expected surge currents in the equipment that will be running on the generator. A surge current is a situation in some equipment's where the starting power consumption is massively larger as compared to their normal working load. The second reason is the introduction of harmonic current which is a result of non-linear electric loads [43]: This result in the rise of temperature of the equipment (in our case generator) and excessive heating might cause the life expectancy of the equipment to decrease. The rise in the temperature of the generator must be kept in mind i.e. generator must be large enough to accommodate the temperature. As the generator will be running/ charging the UPS as well the generator must be large enough to facilitate UPS power rating. Another consideration is that when the generator starts it requires some time to synchronize with the connected Load, if the generator is working on full capacity there are chances that it might drop some load which is quite undesirable in our case. Keeping in view the above factors it is wise to specify a larger generator then the calculated load. A generator with larger capacity then the apparent size will be helpful in handling surge currents, harmonics, and temperatures and can cater the need of handling extra load in future if required.

**QUICK CHECKLIST**

- How would failure of a certain equipment effect the organization?
- Identifying the different level of protection required for different electrical
- Calculating UPS Size.
- Calculating Generator size, keeping in view, surge current, UPS power efficiency, harmonics, synchronizations, operating temperature and future electrical loads

**Total Load and Power consumption of Anyware-DC**

We are considering 25 laptops for our simulation and each server accommodates 25 users. Following Anyware rule a single user may have more than one VM but cannot do so on same server, i.e. a single user may have multiple VMS's but on different servers [Anyware]. Based on table [1] the total load and power consumption of our system is calculated and presented in the table below.

| Equipment | Load | Quantity | Total Load |
|---|---|---|---|
| **Laptops** | 24W | 25 | 600 |
| **Server** | 11W (per user) | 25 users | 275 |
| **Switch/Router** | 8 W | 1 | 11W |
| **Anyware-DC** | | | 886W |

Table 7

## 3.9. Calculations:

The section provides the calculations and Anyware-DC's equipment power consumption keeping in view the total power consumption of Anyware-DC Tab (7)

Calculation of UPS (INVERTER), Batteries Used for Backup & Energy consumed in charging

### 3.9.1. Calculation of UPS:

For our simulations we assume a UPS that will be capable of providing 3 hour continuous Backup. To calculate the size of batteries required, and the energy that will be consumed by charging those batteries via main, we take help from Tab (3) and Tab (4):

As the Ups will only be providing backup to the server and router the total Load will be

Total Load= 275+11=286 (Servers=275; Router/Switch=11)

Required Backup= 3 Hours

Voltage= both for 12V battery and 24V battery.

**1st Step: Calculation of UPS (INVERTER):**

For UPS calculation take 25% of total load and then add it to total load (This is done to reduce aging effect). i.e.

25% of total load=286*0.25= 71.5 approx. =71

Now adding it to total Load we get 286+71=357.5 or 357

Note: For UPS, voltage of both UPS and battery should be same otherwise it will not work i.e. for 24V

Voltage rating UPS we have to use 24V Batteries and for 12V UPS we have to use 12V battery.

Now coming to batteries used for Backup.

**2nd Step: Batteries Used For Backup:**

As there are both 12V and 24V rating UPS so we will be doing the calculations for both 12V and 24V Voltage rating.

For 12V Battery: in order to get the appropriate value for our required backup, we have to suppose the current value that will be required , A/H ampere Hour being the unit for electric charge that is used in measurements such as electrical batteries. For accurate calculation of the energy delivered requires integration of the power delivered (product of instantaneous voltage and instantaneous current) over the discharge interval.[wiki A/H]

- Let suppose A/H=100

  Then As we know that P=IV=100*12=1200.

Even though UPS batteries comes with a manufacturers tagged ratting, and it is considered that the batteries will provide the same rating till the end, in real that is not true as battering life declines with time. This effect is known as aging effect of a battery. Per IEEE standards for battery sizing a 25% increased capacity i.e. aging factor should be added when sizing the batteries [44]

Now in order to find backup divide this value by Total load after addition of aging effect.

So, 1200/357=3.36 i.e. almost 3 hours and 37 minutes.

- Now Suppose A/H=80

  Repeating the same procedure as above

  P=VI=12*80= 960

  So, 960/357= 2.69 which is approximately 3 hours. (Best option for our requirement)

Doing the same calculations for a 24V Battery:

Here as well we will suppose the value of current in order to get the best values for backup. Here we will take the best value straight away i.e. 40A/H

(Procedure is same as done above except the value of Voltage which is 24 here)

As we know that P=VI=24*40=960

In order to find backup divide this value by Total load after addition of aging effect.

So, 960/357=2.68 i.e. almost 2 hours and 60 minutes.

Note: Only 12V batteries are available in Market so in order to get voltage of 24V one need to take 2 batteries of 12V and connect them in series, although the current value of both batteries should be same.

**3rd Step: To Find the Energy consumed In Charging:**

Power is the instantaneous measurement of energy per unit time. The amount of power consumed would depend on the amount of current flowing into the battery, and its voltage at that time [45] . Now to find the energy/Power consumed in charging we will mainly consider the current value of battery as while charging it only uses 1/10 of its current. [46]

So, for a 12V battery current value for 80A/H will be

80/10=80. Now for Power consumption use formula

P=VI=12*8=96 W/H

**Time required for charging the Batteries:**

Here is the formula of Charging Time of a Lead acid battery.

Charging Time of battery = Battery Ah / Charging Current [47]

T = Ah / A

Suppose for 80AH battery,

First of all, we will calculate charging current for 80 Ah battery. As we know that charging current should be 10% of the Ah rating of battery. [48] [46]

So charging current for120Ah Battery = 80 x (10/100) = 8 Amperes.

But due to losses, we can take 8-10 Amperes for charging purpose.

Suppose we took 9 Amp for charging purpose, then charging time for 80Ah battery = 80/ 9 = 9 Hrs. but this was an ideal case, practically its noted that 40% of losses (in case of battery charging)

Then 80 x (40 / 100) = 32 …..(80Ah x 40% of losses)

Therefore, 80 + 32 = 112 Ah (120 Ah + Losses)

Now Charging Time of battery = Ah/Charging Current

112 / 9 = 12.44 or 12 Hrs.’ (in real case)

Therefore, an 80Ah battery would take 12 Hrs.’ for completely charging (with 9A charging current).

Table 8

| UPS | Calculations |
|---|---|
| **Load (including Losses)** | 357 |
| **Battery** | 12V |
| **A/H** | 80 Ampere Hour |
| **Backup time** | 3 Hours |
| **Battery Charging Power** | 96Watts/Hour |
| **Battery Charging time(Full)** | 12 Hours |

### 3.9.2. Generator Calculation:

As most of the USP nowadays are 90-95% efficient and considering the 25% aging effect of UPS, whereas most laptops are around 75%, we assume the Power Factor as 8 for ours architecture. To calculate the total load the generator will be backing up= UPS+ Laptops + Servers +Router

= 96+ 886= 982 Watts

**Formula:**

In order to calculate the size of the Generator we need to convert our total Load to KVA or VA

$S_{(kVA)} = P_{(kW)} / PF$

As 1 Kw=1000 W so to converts Watts into Kilo Watts

P (Kw) =P (W)/1000

Dc-Anyware Load in Watts = 982+ losses (25%) =1200 W

PF= .8

**Watts to Kw**

$P_{(Kw)} = P_{(W)}/1000$

$P_{(Kw)} = 1200/1000$

$P_{(Kw)} = 1.2_{KW}$

**Converting Kw to KVA**

$S_{(kVA)} = P_{(kW)} / PF$

$S_{(KVA)} = (1.2) / (.8) = 1.5_{KVA}$

The total Load with Losses is 1.5 KVA, so considering the reasons presented in Section (3.5) to keep the generator size larger than the apparent Load, we almost double the size of generator in order to handle any sort of extra load or losses.

Generator Size for Anyware-Dc= $2.2_{KVA}$, the fuel consumption and other calculation for the Generator is presented in Chapter 4.

Table 9

| **Generator** | |
|---|---|
| **Load(including Losses)** | 1200W |
| **Load in Kw** | 1.2KW |
| **Load in KVA** | 1.5KVA |
| **Generator Size** | 2.2KVA |

# CHAPTER: 4 RESULTS & EVALUATION

## 4.1. Overview:

This chapter evaluates the Energy Consumption, Energy savings and an overall efficiency achieved by implementing Anyware-DC. The results are acquired through a discrete event Simulator Design that get energy consumption values of different components on hourly basis and calculates the power consumption per Hour over a total 24-Hour period. Written in Python the simulator evaluates the benefits of using Anyware-Dc in a typical scenario of developing countries where power outages are frequent. The simulator works on pre-specified policy of power interruptions occurring in overall 24 hours and calculates the changes in energy consumption accordingly.

The power consumption variable values for components are specified using the calculated values in chap3. The simulator simulates the scenarios described in section of chap 3, i.e. When power is supplied by main grid, Anyware-Dc backed up by UPS, Anyware DC backed up by generator. For UPS case UPS discharge battery has been set on a 30 minutes threshold value, i.e. as soon as the UPS is only left with 30 minutes backup, the Generator kicks in (in case of prolonged power cuts). The UPS batteries are intentionally set on the threshold level and are not allowed to drain out completely, so to save the batteries from frequent drain outs which may cause the UPS batteries life to shorten. The main switch statements of the simulator are

- As soon as there is a power outage and there is more than 30mins backup in UPS battery, switch the control to UPS
- If there is power outage and the UPS is below threshold level, Switch to generator (while UPS only runs for some milliseconds to allow safe switching of load to generator without any interruption)
- In a power outage scenario, if the laptop flag is on i.e. any of the laptops battery power is lower than the specified threshold value, switch to generator.
- When UPS is discharged, and Main Grid or Generator are acting as the power Source, The UPS gets charge.
- When main grid is supplying Power and UPS has almost complete charged battery, it still consumes some percent (3-5%) of charge.

Evaluation is done by a comparison between the power consumption and energy efficiency of a traditional Anyware and Anyware-Dc, between Anyware-DC and desktops, Anyware-DC and Anyware-UPS, all the results are plotted on 24 hour basis with Random as well as fixed interval of Power outages. The Simulation results also aid in evaluating the overall effect of laptop batteries in Anyware-Dc efficiency and how much does UPS Backup contributes to efficiency of Anyware-Dc.

To evaluate how the traditional Anyware will perform in environments where power outages occur, we connect a UPS and generator naively. We call this architecture as Anyware-UPS.

The different Calculations for Anyware-UPS are presented in Section [4.1.1] based on the total Anyware-UPS Load and the equipment backed up by UPS and Generator during Power outages, using table [8], [9] and the formulas used in section 3.9.

### 4.1.1. Anyware-UPS Calculations:

**UPS Sizing for pure Anyware**:

In case of Anyware's UPS battery sizing we assume two cases:

1. Using same sizes of batteries/ battery by keeping the current (A/H) used for charging the UPSes backing up Anyware-Dc and Anyware-UPS same.
2. Calculating the current (A/H) required for UPS batteries which will provide a 3 hour backup to Anyware-UPS.

For UPS calculation take 25% of total load and then add it to total load (This is done to reduce aging effect) i.e.

25% of total load= 886*0.25=221.5

Now add it to total load, so 886+221.5=1108

For 80 A/H (used for DC-Anyware)

=.86 approx. 1 hour

For 3 hour backup

Using 280 A/H will result in a 3 hour Backup

Table 10

| UPS Backup (hours) | Ampere Hour | UPS charging Power | UPS charging hours |
|---|---|---|---|
| 1 | 80 | 96 W | 12 |
| 3 | 280 | 336W | 12.15 |

## 4.2. Energy Savings of Anyware-DC:

We evaluate the system by simulating the architecture for random power outages in range of 0 to 99 percent power outage probabilities over period of 24 hours. The power outage over the period of 24 hours is simulated at the start of every hour, based on some probability. The scenario assumed by the simulator is that all laptops and the UPS have a backup of 3 hours, while in case if any laptop runs out of battery or ups batteries reach its threshold level, a standby generator is present large enough to provide backup to the whole infrastructure.

Fig (7) plots the energy efficiency by implementing Anyware-Dc in comparison to Anyware, to no Anyware and Anyware-UPS. On y-axis of the plot is the gain or loss in efficiency (in percent) and x-axis depicts the different power-outage probabilities each simulated over a 24 hours period. The blue line shows the gain in efficiency of Dc-Anyware when compared to desktop architecture; the orange line shows the gain in energy efficiency by Anyware-Dc as compared to Anyware and the green line shows the efficiency when Anyware-Dc is compared to Anyware-UPS.

The blue line shows the result of efficiency gained by implementing Anyware-Dc as compared to desktop architecture. The line shows that Anyware-Dc is as efficient as Anyware was that is gaining around 80% of efficiency as compared to a typical desktop computing architecture.

In case of Anyware-dc to Anyware comparison, with increase in power outage probability the efficiency of Anyware-Dc increases. The reason for slow incline of efficiency at the start is the minimum usage of UPS/ laptops batteries. For below 20% of probability the system does not gain much efficiency as compared to pure Anyware. But from 20% onward it gradually gains efficiency as the laptops and UPS batteries backup is utilized to its maximum capacity during a power outage while UPS supplies power to the server, hence saving energy during that period of time. The plot shows energy savings between 15-18% for Anyware-Dc as compared to simple Anyware.

The Orange line shows the gain/ loss in energy efficiency when using Anyware-Dc as compared to when using Anyware-UPS, for different power outage probabilities. The line shows gain in efficiency for our proposed architecture in comparison to when using the basic version of Anyware backed up by a UPS and generator in case of power outages i.e. Anyware-UPS. The results shows an average 33% efficiency gain for Anyware-Dc , with an efficiency increase up to 37% for longer period of power outages. The main reason for the increase of efficiency for higher power outage probabilities values is the maximum utilization of UPS for our proposed architecture and the smaller overhead of the smaller backup during Main hours, whereas a larger overhead and minimum utilization of UPS in case of Anyware-UPS

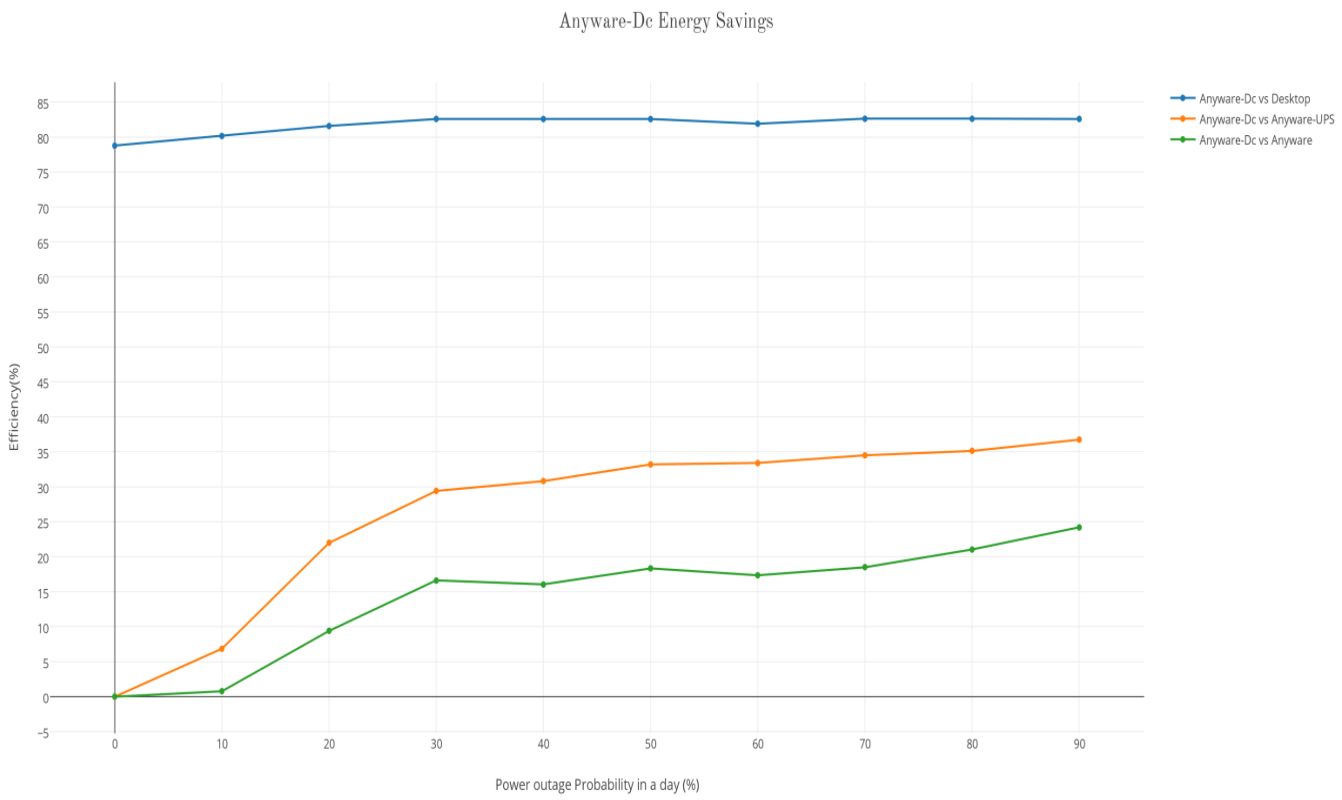


Figure 7

From figure 4 it can be concluded that the increase in Anyware-Dc energy efficiency is directly proportional to the maximum usage of UPS during power outages. The longer the UPS runs the greater the efficiency. This is due to the fact that during UPS operation energy consumption is almost 0 hence the overall consumption per day including this period of time reduces significantly. In order to maximize the Backup of a UPS for our architecture, we require Laptops with longer Batteries backups. The hurdles in choosing UPS batteries with larger Backup are the Laptop Backup and the added UPS charging power. Next section present results to evaluate the effect of increased UPS backup time and longer laptop Battery Backup on performance of Anyware-Dc.

## 4.3. Effect of Batteries Backup:

The plots in this section evaluate the effect of laptop and UPS batteries on the performance of Anyware-DC in case of power outages. As the Ups Backup increases, for both Anyware-Dc and Anyware-UPS the charging current required to charge the batteries increases hence resulting in greater Power Consumption for charging the batteries. I.e. for Anyware-DC

For 3 hours ups battery charging current is 96 W/hr.

For 4 hours battery charging current is 120 W/hr.

For 5 hours Battery charging current is 168 W/hr.

In fig (8) on x-axis of the plot we have laptop backup (in hours) and on y-axis the gain in efficiency (%) for respective backups values. Each laptop backup value is evaluated individually for the 3 different UPS backups 3hrs, 4hrs and 5hrs available, shown by the different legend colors in the plot. The power outage pattern is Random for each hour depending on the power outage probability over the 24hours.Even when UPS is fully charged we assume it still gets 5% of its total charging power consumption(in case of any losses or current leakages).

The simulation results shows an average of 36% of efficiency for 5 hours of ups backup, 33% percent for 4 hours of UPS backup and 32% for 3 hours UPS backup. The maximum efficiency i.e. 40% is gained by keeping the Backup of UPS 5 hours and Laptop 7 hours. The gain in the efficiency for the laptop backups 1-7 remains almost the same except for when the laptop Backup is 0 no efficiency is gained in case of any of the UPS backups .For 0 backup of Laptops the UPS does not operate at all in case of power outages and the architecture runs on either Main supply or Generator, adding up the 5% overhead of UPS charging as well, hence the gain in efficiency is very minimal or equal to 0.

While keeping the laptop backup =1 and increasing the UPS backup upto 7 hours the efficiency increases accordingly, although the in each case the UPS will run only for 1 hour and then either generator or main power will provide the Supply, but the UPS with longer backup results in more efficiency as compared to smaller UPS because, for the next power outage, i.e. when the Laptop gets charged and is above the threshold level, the UPS with longer backup will be utilized while using very little power consumption for charging purpose as it won't drain out as early as UPSes with lower Backups.

Fig (9) is an extension to fig (8) plot with ups backup values upto 7 hrs. . The pattern shows that the larger the UPS Backup the more is the gain in efficiency, especially for instances where the laptop backup is maximum as well, as in that case the UPS with larger Backup is utilized to the maximum without putting on the load on the generator in case of a laptop falling below its threshold level during power outages as the laptops have longer battery life. The average efficiency for UPS having 6hrs Backup and 7hrs backup keeping Laptop Backup 1 is around 1%. In all three cases the Backup will switch from UPS to generator after 1 hour of power outage. After 1% laptop backup value, the results shows that the efficiency increases with the increase in UPS backup and Laptop Backup, an average of 31% for UPS backup=3 hours with gaining the maximum efficiency up to 32.6%, for UPS backup=4 hours the average efficiency is 33% while the maximum is 34%, for UPS backup=5hrs the average efficiency is 36.65 while a maximum of 40% efficiency keeping laptop Backup=7 hours. for UPS backup =6 hours and 7 hours the average gain of efficiency is 38.36% and 39.80%, while a maximum of 42% and 44% efficiency is gained with laptop Backup=7 hours. The random pattern of efficiency for Laptop backup between 2 to 7(hour) is due to the power outage probability being random.

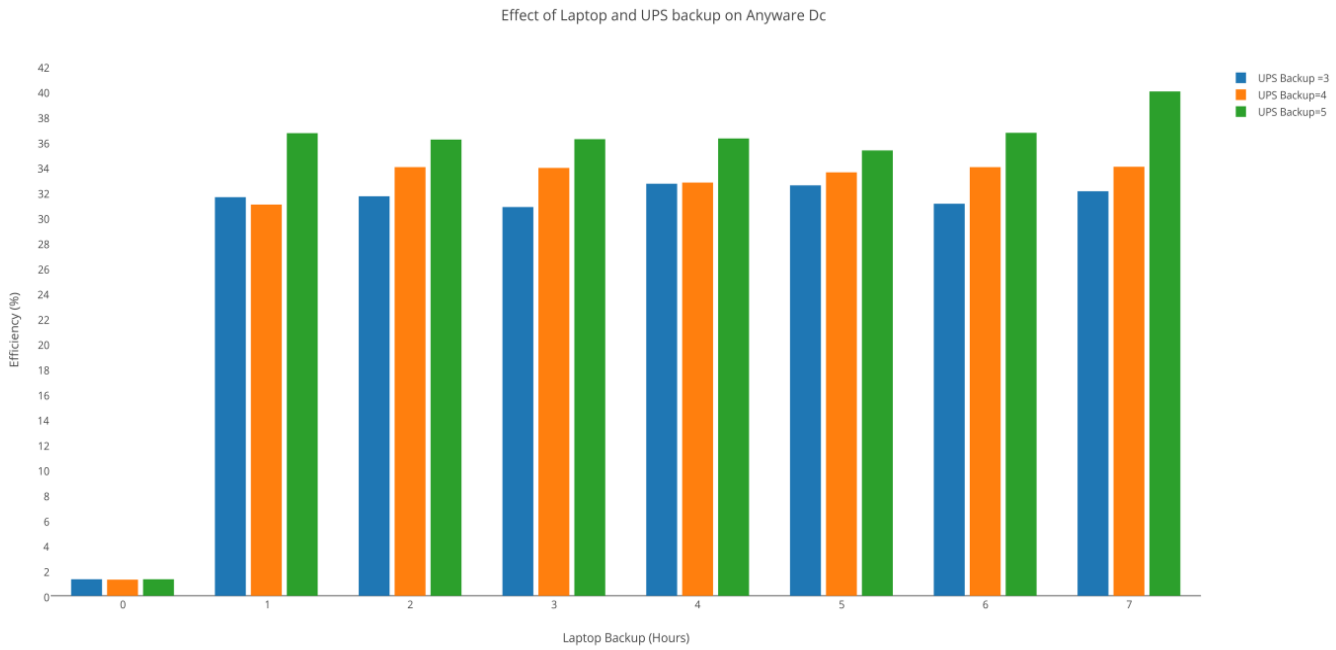


Figure 8

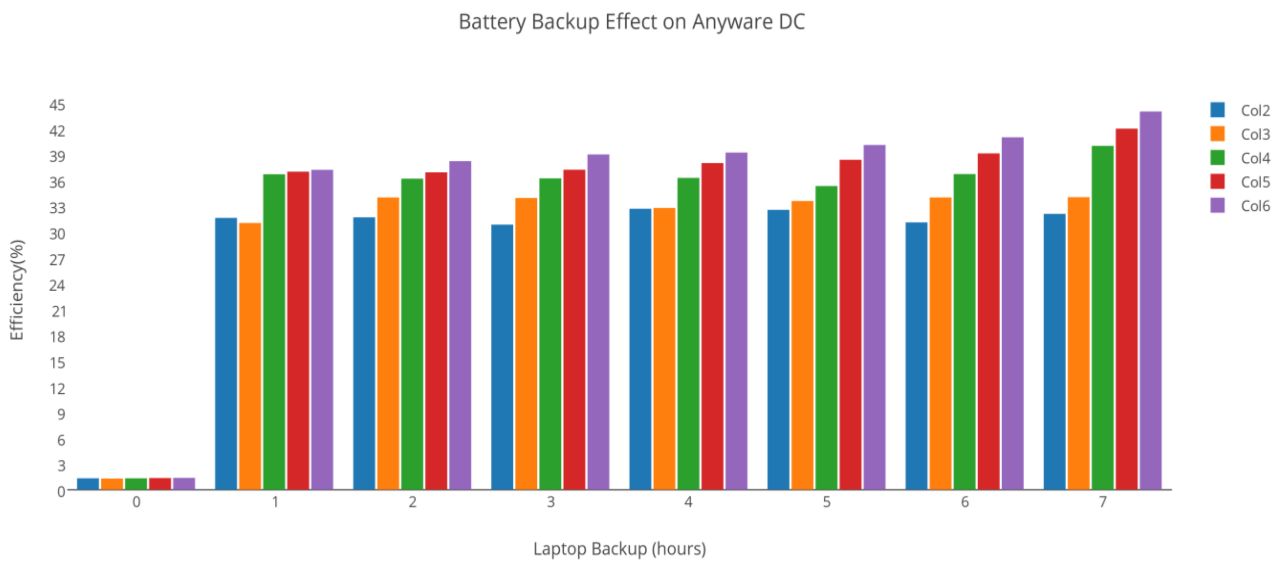


Figure 9

The above plots show that a laptop with a backup less than 1 hour will not result in any efficiency while laptops with longer backup will affect the efficiency positively. The reason that laptop Backup does not have as much effect on efficiency as UPS is that even if the Laptop does have a longer battery but the UPS is of smaller size, the maximum utilization of UPS during power outages won't be possible. So a combination of longer Backup of laptop and UPS backup will be idle i.e. for laptop backup =1 hrs. and UPS Backup=3 hours the average efficiency is 30%,31% and 36% for 3hours ups , 4hours and 5 hours UPS backup respectively. As compared to 32%, 34% and 40% for laptop Battery with Backup= 7 hours. The effect of UPS battery backup is similar. With smaller UPS batteries, the infrastructure must switch to generator backup immediately. This leads to lower energy efficiency. However, with a longer UPS battery life, the infrastructure can continue running without generator backup for much longer, resulting in high fuel efficiency

The reason that UPS with longer Backup does result in more efficiency then a UPS with smaller Backup even for 1 hour or 2 hour UPS backup is that the UPS with longer Backup will require more time to discharge completely as compared to a Backup with smaller Backup, and the only hindrance to utilize the UPS will be the laptops to get charge above the threshold level, so for next period of Power outage the UPS will still have enough Backup to run while consuming less charging time and hence less power to get charged during main as compared to a small backup UPS which will be completely drained after use of some hours.

## 4.4. Fuel Consumption:

In this section we evaluate the reduction in fuel consumption achieved by using Anyware-DC. The plot shows the fuel consumption of all three architectures i.e. Desktop, Anyware-UPS, Anyware-DC. The fuel consumption is calculated in litter per hour, for 100 and 75% load. The reason for calculating for both 100 and 75% of load is that most of the time losses and external factors affect the load, for which we have chosen a generator almost twice the size of our load. The 100% Load represents the scenario where a large no of losses and external factors are added up to the load and the generator is utilized to its full capacity, while the 75% shows the consumption for our actual load (with standard 25% losses).

Figure 10 presents the plot for fuel consumption for all the three architectures with blue bar presenting the fuel consumption of Desktop architecture, orange bar for Anyware-UPS and Green bar for Anyware-DC for 100% load, at different power outage probabilities. On the x-axis of the plot is the power outage probability for 24 hours, while on the y-axis is the fuel consumption in litters (per hour).

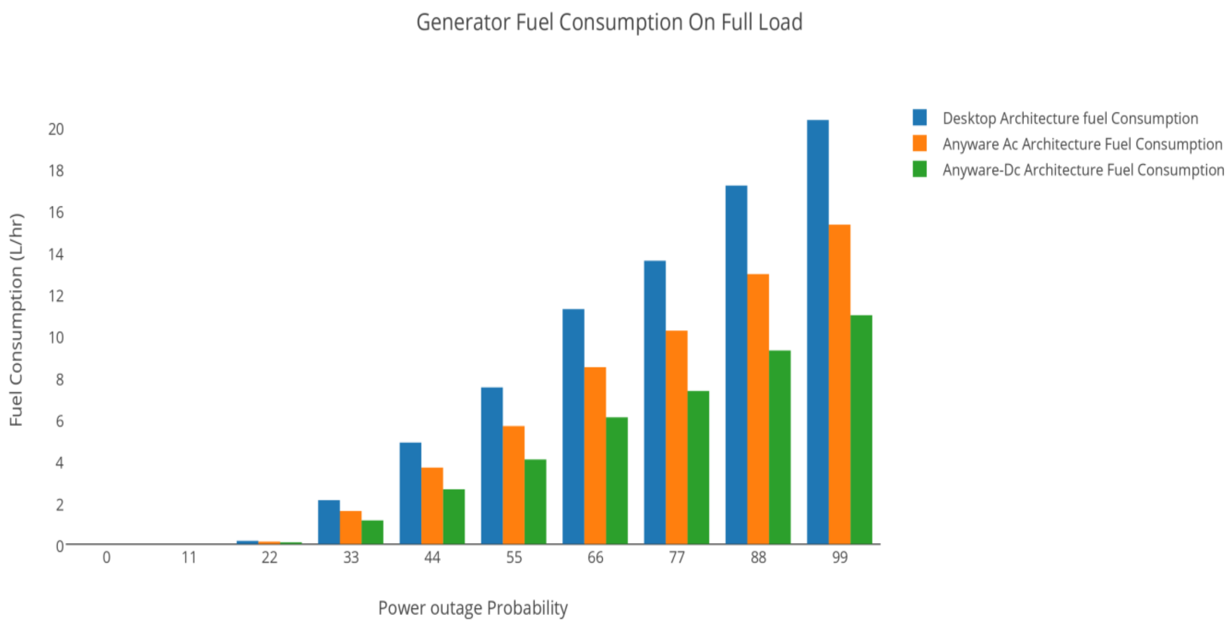


Figure 10

Figure (10 ) shows that desktop architecture consume twice as much liter/ hour as Anyware-Dc whereas when compared to fuel consumption of Anyware-UPS our proposed architecture still consumes significantly lesser fuel. The fuel consumption for desktop architecture ranges from 2 liters upto 21 liters per hour, whereas for Anyware-UPS 2 liters to 15 liters per hour while for our architecture the fuel consumption ranges from 1 to 11 liters per hour. The fuel consumption increases with increase in overall power outage probability as more power outage means more utilization of Generator as UPS will not get maximum time to get fully charged and hence generator will be utilized. For power outage probabilities from 0-22% the fuel consumption of all three architectures is very low because of the minimum utilization of Generator.

Figure 11 shows the effect of Laptop Backup on the fuel consumption of Anyware-DC. The power outage is random for a given probability value for each laptop backup value and Load over a period of 24 hours. The x-axis of the plot has the laptop backup value and y-axis has the fuel consumption (in liter per hour) .we can estimate from the plot that as the laptop backup increases the fuel consumption decreases, i.e. for maximum laptop backup i.e. 7 hours our architecture will consume around 2 liter per hour for 75% load and 5 liter per hour for

100% load. While in worst case scenario where the laptop backup is 0 the simulation results show that the architecture will consume around 12 liter of fuel per hour for 100% load and around 6 liter per hour for 75% Load.

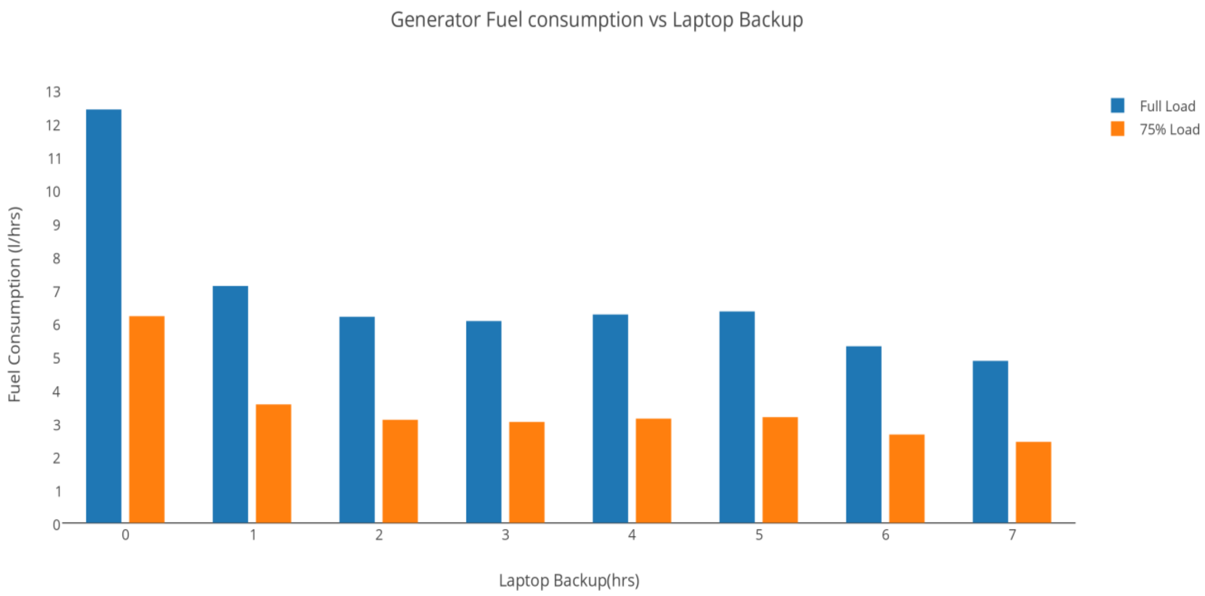


Figure 11

The plots show that Laptop Backup and UPS Backup play an important role in acquiring maximum efficiency in case of Anyware-Dc and reduction of Fuel Consumption.

## 4.5. Power-Outage Scenarios of Pakistan:

In this section we evaluate the performance of our architecture for the current power scenario of Pakistan's Rural and Urban areas. Currently Pakistan's urban areas have a 1 hour power outage after every one hour, making it up top 50% of power outage probability in 24 hours whereas the Cities are facing a 1 hour power cut after every 3 hours, which sums up to 25% of power outage in 24 hours for Urban areas.

The figures in this section plots the results for both cases of Anyware-UPS i.e. where UPS backup is almost 1 hour (keeping the battery current at 80AH and size same for both Anyware-UPS and Anyware-DC , in which case the UPS will provide only 1 hour backup to Anyware-UPS due to larger load and smaller battery size) and for the UPS which provides a 3 hour Backup to Anyware-UPS with large battery which will require a greater value of battery current up to 380 AH to charge those batteries, hence resulting in larger battery charging power.

Calculations: As the Ups Backup increases, for both Dc and Anyware-UPS the power and charging current required to charge the batteries increases as well i.e. for Dc-Anyware:

For 3 hours ups battery charging current is $96_{W/h}$

For 4 hours battery charging current is $120_{W/h}$

For 5 hours Battery charging current is $168_{W/h}$

For Anyware-UPS

3 hours Backup…ups battery charging current is $336_{W/h}$

4 hours Backup…. Ups battery charging current is $393.6_{W/h}$

5 hours Backup… ups battery charging current is $508.8_{W/h}$

In figure 12 the light grey areas in the bar represents Dc-Anyware efficiency in rural areas which is 18% and 19% for Urban Areas of Pakistan. The dark grey area shows the in-efficiency of Anyware-UPS to be around -3% for urban areas and -3.20% for rural areas. The black shaded Region shows the in-efficiency of Anyware-UPS when UPS backup is 3 hours, which is up to -3.20% for urban areas and -15% for rural areas. The reason for the greater in-efficiency of the black area(Anyware-UPS with 3 hours Backup) as compared to the light grey(Anyware-UPS with 1 hour Backup) is the higher battery charging power that is required to charge the heavy current batteries of the UPS (3hours backup) for the Anyware-UPS.

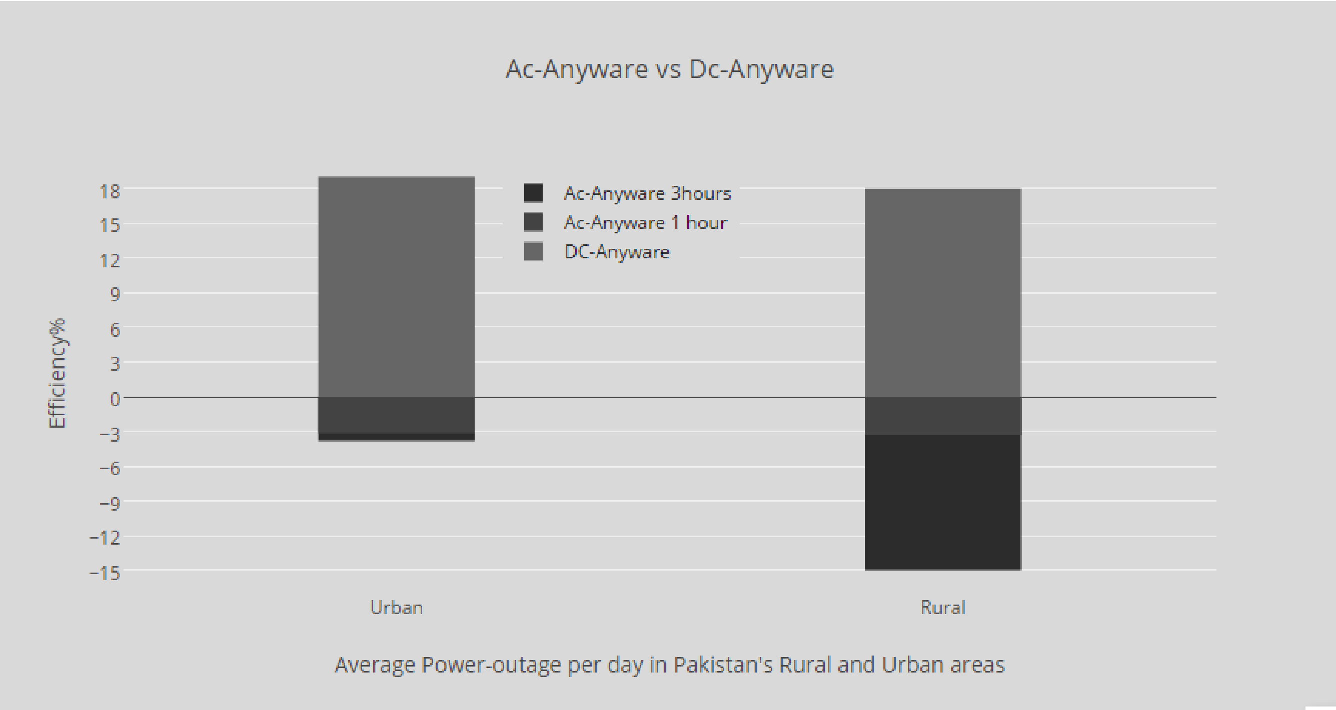


Figure 12

Plot 13 is an extension to Figure (12), the two scenarios shows the efficiency calculated over fix and random intervals of power-outage. The reason for simulating for random and non-random both scenarios is to show that random power outage scenario will result in a random pattern plot. For fixed-interval for rural areas the power goes out after every 1 hour whereas for urban areas the power cuts happens after every 3 hours interval, whereas for Random scenario in urban areas random 25% power-outage occurs over 24 hours period and 50% for rural areas.

The reason for increased efficiency of Dc-Anyware in rural and urban areas for random power-outage is the maximum utilization of ups (as the power might be off for constantly 2-3 hours unlike fixed 1 hour interval), so is the reason for negative efficiency of Anyware-UPS

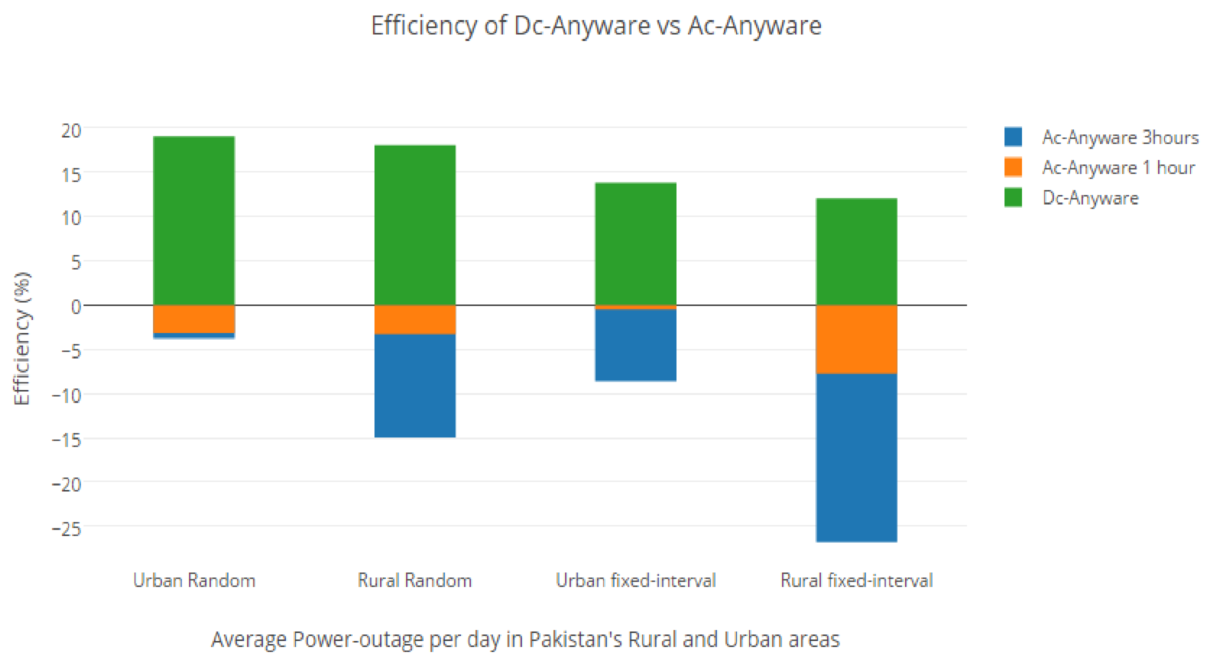


Figure 13

In figure (14) the graph provides an over-view of the overall efficiency of Anyware-UPS (with less than 1 hour ups backup and 3 hours ups backup) and Dc-Anyware (with 3 hours ups backup) for Rural and Urban areas over fixed and random power-outage intervals in 24 hours.

The increased efficiency of Dc-Anyware in rural areas as compared to urban areas is due to the maximum usage of UPS. The increase in negative efficiency of Anyware-UPS when the ups backup is 3 hours is because of the added up value of Battery charging power.

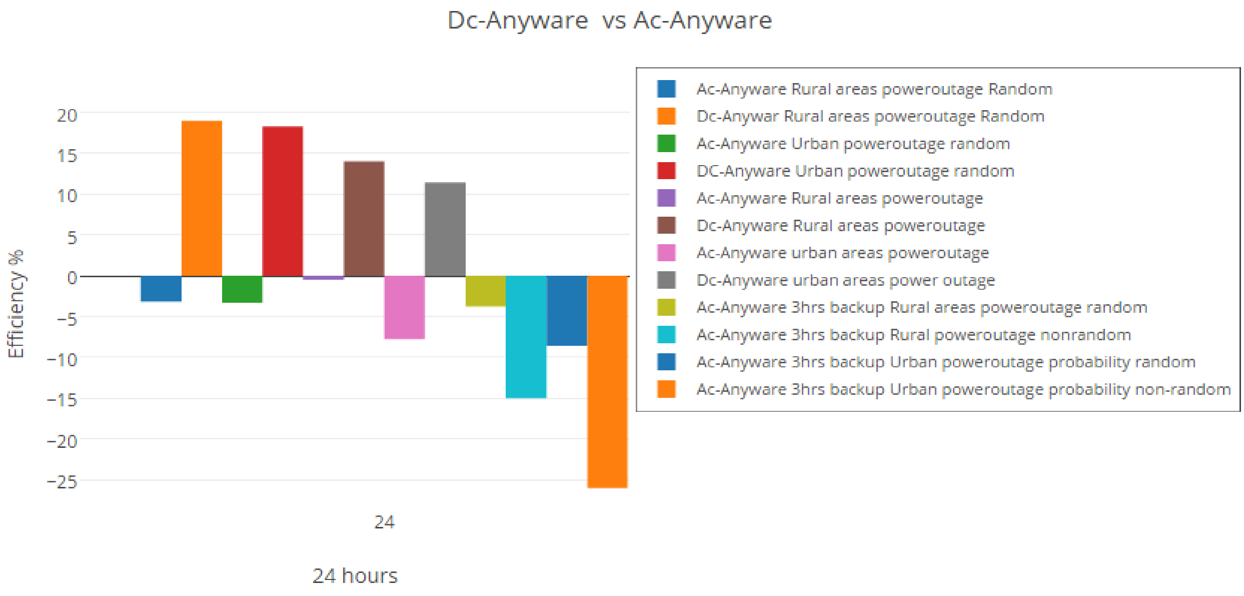


Figure 14

Plot (15) and (16) shows the effect of Laptop and UPS batteries on Anyware-DC for Rural and Urban areas. For Rural areas the plot shows an efficiency gain between 15 to 20% for our architecture, while even for environments with smaller periods of and less frequent power outages such as Urban areas in this Scenario having only 25% of power outage probability in a day, The architecture shows upto 15 % and higher energy efficiency for laptops having Backup greater than 0.

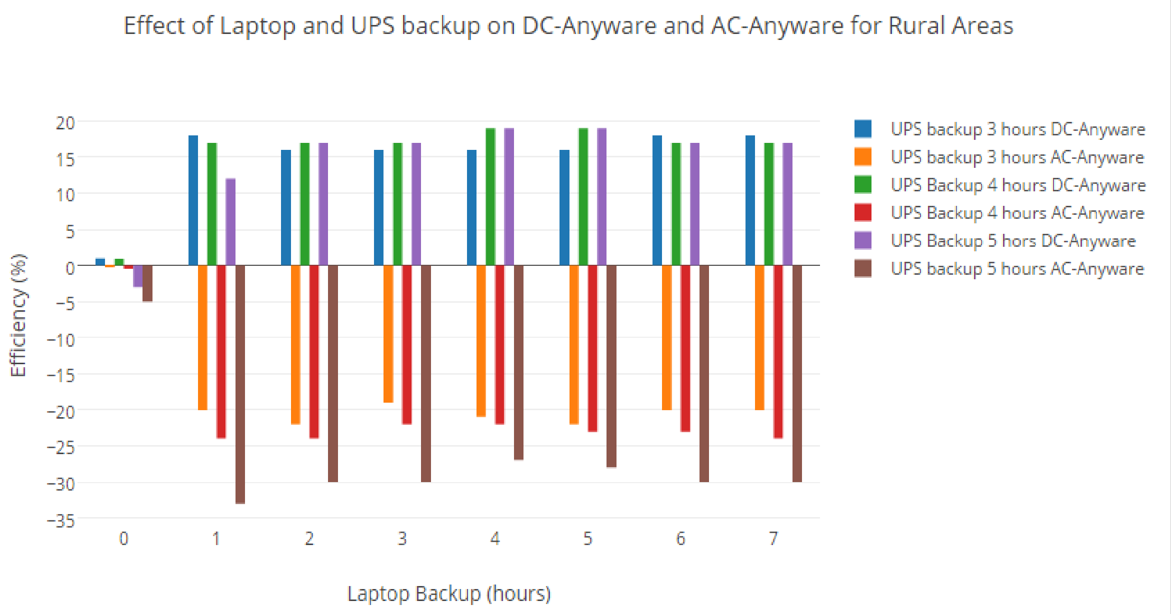


Figure 15

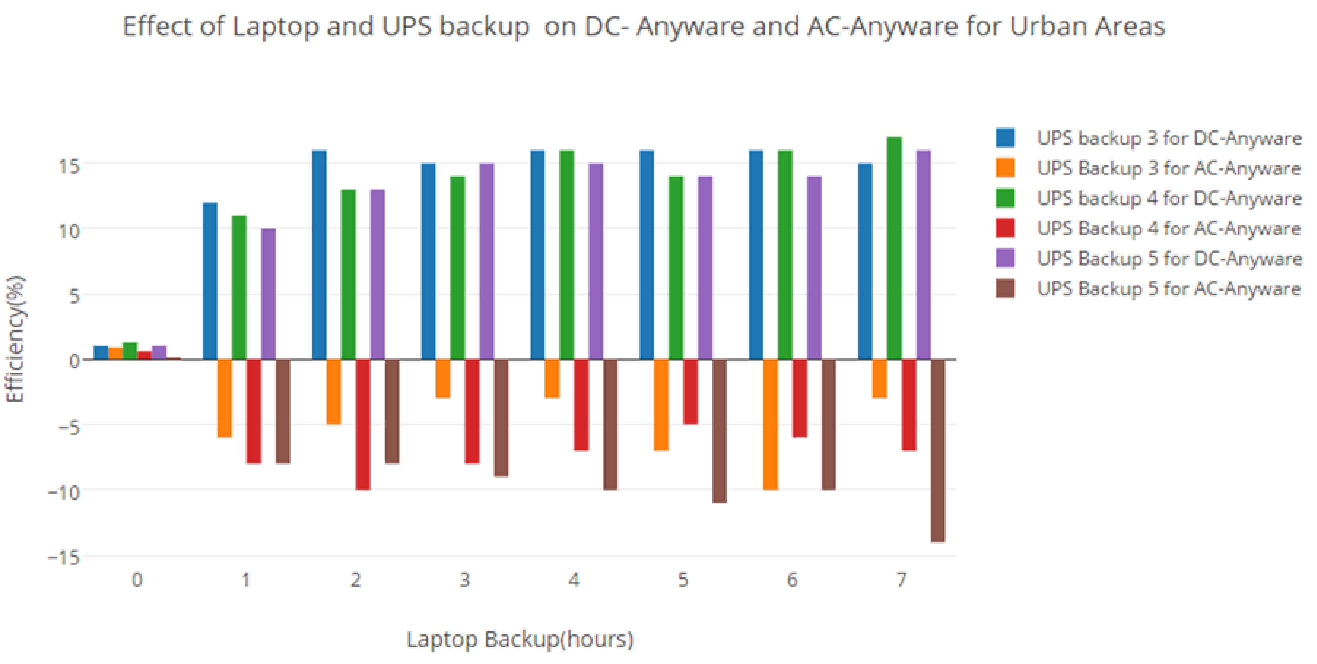


Figure 16

The reason for in-efficiency of Anyware-UPS is the greater power required for UPS battery charging. The longer and frequent the power outages the greater will be, the higher the in-efficiency for Anyware-UPS.

The results show that Anyware-DC achieves higher energy efficiency as compared to Anyware, Anyware-UPS and no Anyware.

Overall our architecture shows up to 20% of increase in efficiency as compared to pure Anyware. When compared to no-Anyware or traditional desktop setup, the simulation results shows around 80% increase in efficiency for Anyware-DC. After simulating the energy consumption of Anyware-UPS the resultant plots shows Anyware-UPS to be in-efficient up to -5% when deployed in environments for which Anyware-DC is proposed.

The energy savings presented in the plots are subject to our specific selected equipment that we are using for our architecture. Chap 3 section [3.5] provides an overview of the equipment selected their power consumption and other numbers, with the basic insight being that each central server serves 25 VM’s.

# CHAPTER 5: COST ESTIMATION:

Our architecture can easily be implemented in an already established and running computing enterprise with ease and minimal cost. Most of computing enterprises already have a centralized architecture for which servers and switches are deployed in the enterprise. Keeping in view the power scenario of Pakistan and the criticality of systems, equipment in a computing enterprise's, most of enterprises maintains some kind of backup mostly a large generator. As laptops are more portable and now easily available in lower cost, majority of the employees of an enterprise already possess a laptop, so utilizing an employer's personal laptop can be an option. But due to the privacy policies and issues of an enterprise it will be better to invest in buying new laptops for employees instead of Desktop PC's.

In order to implement our proposed Architecture from scratch in an enterprise, a rough cost estimate for our proposed architecture [49] [50] [51] [52] is given below. Note that much of this cost can also be offset by re-selling the equipment the enterprise already has.

Table 11

<table>
<tr><td colspan="2">Project Name</td><td colspan="2">Anyware-Developing Countries</td></tr>
<tr><td colspan="2">Date of Estimate</td><td colspan="2">11/06/2015</td></tr>
<tr><td colspan="2">Equipment</td><td>Quantity</td><td>Total Price for this quantity (PKR)</td></tr>
<tr><td colspan="2">Laptops</td><td>25</td><td>1,250,000</td></tr>
<tr><td colspan="2">Server</td><td>01</td><td>126,000</td></tr>
<tr><td colspan="2">Router/Switch</td><td>01</td><td>4319</td></tr>
<tr><td colspan="2">UPS</td><td rowspan="2">01</td><td rowspan="2">19,000</td></tr>
<tr><td>Battery</td><td>Inverter</td></tr>
<tr><td colspan="2">Generator</td><td>01</td><td>25,000</td></tr>
<tr><td colspan="2">Total Cost</td><td></td><td>1,424,319</td></tr>
</table>

# CHAPTER 6 CONCLUSION

## 6.1. Conclusion

This dissertation presented Anyware-DC, an architecture proposed for developing countries to achieve and enable energy efficiency in computing organizations and enterprises in presence of power outages. Modifying the idea of Anyware, this research informs the purpose by building a simulator to collect the energy consumption of the proposed architecture for different scenarios of power outages. From the energy consumptions calculated via the simulator we evaluate the efficiency of our system in different scenarios during power cuts.

The basic idea was to enable energy proportionality even in the presence of power cuts, by utilizing the energy that is wasted by usage of heavy desktops during low utilization periods in enterprises by replacing desktops with laptops without sacrificing on the performance.

Chapter 2 presented the related work in field of green computing, and why do we need a light weight client architecture in the presence of Thin Clients and other existing green computing Solutions. The chapter discussed that thin clients due to their limited local resources might be a good option for replacing desktops by consolidating their workloads on a remote server and utilizing remote resources hence resulting in saving energy and enabling easier management. But the main drawback of thin clients is their complete dependence of processing on remote resources which might result in limited productivity of local resources and compromising on user experience and performance.

As the power draw of most thin clients is almost the same as that of a Laptop, an architecture which can combine the workload consolidation of thin clients with the local resources of a laptop would be an ideal system for saving energy.  This idea is presented in Anyware Architecture. However this system, when implemented in environments where power cuts are frequent, fails to perform effectively. Our main insight was to design a similar architecture such as Anyware for environments where power outages are frequent, by providing some kind of Backup source during the power outages without compromising on the efficiency or performance. Our proposed design leverages the fact that by utilizing the built-in backup of laptops during power cut outs, we can achieve even greater efficiency than Anyware and Traditional Desktops. Chapter 3 presents our proposed architecture Anyware for Developing Countries (Anyware-DC). It provides the overview of Anyware-Dc design, which consists of laptops at one end connected to a Central Cluster of servers via UPS at the other end. The generator acts as the secondary Backup source for the Laptops, central cluster and UPS, whereas the UPS acts as the primary backup source and only backs up the network Cluster during power cuts. The clients utilize the central servers, by running the Anyware application remotely with help of thin virtual machines that resides on the servers for each user. These virtual machines utilize the file systems of clients to enable smooth remote execution. The architecture runs normally when main grid is providing the power to the equipment, but as soon as there is a power cut the Ups switch turn on and backups the central server, while the Laptops run on their Battery backup. The UPS keeps on backing up the servers until Main Supply is back in which case the UPS switch to Central servers turns off and the battery switch to Main turns on hence charging the UPS battery. However, if either the UPS battery or any of the Laptop batteries reaches their threshold level, the generator switch turn on and the whole architecture is backed up by Generator until Main supply returns. In this way the architecture saves the laptop's energy during UPS backup, and less generator fuel is used by making the utilization of generator minimum. The required equipment for this architecture and their energy profile is presented in chapter 3 of this dissertation. Based on the specified equipment for our architecture an evaluation of Anyware-DC is presented in Chapter 4. For Anyware-Dc evaluation we designed a simulator which estimates the energy consumption of Anyware-Dc in case of power outages and a Laptop Battery monitoring application to switch on the generator automatically, in case if any of the laptops runs out of charge during power cuts. In cases where a Laptop has a very low backup life, we suggest in investing new batteries.

Our simulation results showed that Anyware-DC reduces energy consumption up to 80% as compared to traditional Laptops, around 33% as compared to Basic Anyware. These numbers shows that because of smaller load on UPS in case of Anyware-Dc the UPS runs for longer period of time hence reducing the overall consumption of the system over 24 hours significantly. Because the UPS runs for a longer period in case of our architecture the generator is utilized to its minimum. As the Generator sizing calculation show, due to smaller size of the UPS batteries the generator required for our architecture will be of smaller size as compared to the other two architectures, hence the fuel consumption will be less for our case. The simulation results for generator use and fuel consumption for our architecture resulted in decreased running time of generator and hence lesser consumption of Generator fuel. As for developing countries with intermittent power supply a UPS is connected, during the main an overhead will be added to the overall consumption of the architecture in form of Power required for the charging of the UPS. For Anyware-Dc as the UPS batteries are of smaller size the power required for the batteries to get charged will be small as compared to existing architectures, hence the overall overhead added to the total consumption for our proposed architecture will be less.

## 6.2. Discussion:

The dissertation provides a number of opportunities for future work, by practically implementing the proposed architecture in a computing enterprise or universities in developing countries and evaluating the real effect of it. Another good option might be how to increase the UPS backup while keeping the charging current and power required for the larger UPS low. Another option can be to use sealed deep cycle lead acid batteries to deduct the maintenance cost and need for watering required for UPS batteries. As sealed deep cycle batteries don't require any maintenance because of the encapsulation of all the components in a seal also it results in lesser losses during UPS utilization. For our equipment selection we supposed Laptops with an average backup of 3 hours, a good future work option can be to invest in Laptops with longer life backup batteries nowadays available in markets and study the performance of Anyware-DC for it. Another option for future research might be the adaption and implementation of similar architecture for other portable devices such as Mobile phones.

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