A Review - Green Computing

[1]Aniket N Nikam, [2]Shailendra Singh, *Senior Member, IEEE*
[1] Assistant Professor, Department of Computer Science & Engineering
[2] Professor, Department of Computer Engineering & Applications
[1]Shri Guru Gobind Singhji Institute of Engineering and Technology (SGGSIET), Nanded,
[2]National Institute of Technical Teachers Training & Research Bhopal, India.
Email: [1]aniketnikam6791@gmail.com, [2]ssingh@nitttrbpl.ac.in

Abstract — **As the popularity of computational technologies and internet is increasing, consumption of energy has abruptly grown. The requirement of energy all over the world for data centers, computing machines and network is mainly supplied by thermal power plants which use fossil fuel like coal, oil. Those energy sources are nonrenewable hence having a problem is the liberation of green house gases like CO2 in the environment. The energy requirement of data centers is approximately 1.5 percent of the total energy consumption of the entire world. Green computing is the latest area for optimizing energy consumption and reducing carbon footprint which causes environmental problems like global warming and ozone layer depletion. Use of renewable energy needs to be promoted for computer aiming better future. This paper identifies state-of-the-art in green computing and describes areas which have further scope for advancement in green computing. We found three major areas (i.e. hardware, infrastructure, and software); we further categorized three areas into two common cases based on workload of servers: *Idle time* and *Peak time* where energy utilization can be optimized with fulfilling performance criteria. We also found some dominant problems and research challenges in these areas of green computing.**

Keywords— Green Computing; Data centers; Virtualization; Idle time; Peak Time.

I. INTRODUCTION

Green computing nowadays becoming one of the significant area of research. The goal is to optimize efficiency and energy consumption of computing machines, servers, data centers and networks. Hardware level, infrastructure level, and software level are three main areas where energy can be reduced considerably. Latest improvements in hardware like processors have proved to be energy efficient than older ones. The concept of Green networking is introduced to minimize energy for networks and network components. Data center infrastructure, network infrastructure, data center design, type of servers used in data center affects energy consumption and efficiency. Software solutions have more impact on energy consumption [1]. Virtualization proved the fact, It brought revolution in cloud computing. It optimized energy consumption as well as performance.

Cloud services run on hundreds of thousands of servers, which are spread across the data centers worldwide. Google is estimated to own over a million of servers. Microsoft's Chicago data center alone having More than 300,000 servers [2]. Over a 57 percent of electricity power is generated with coal in 2009. Data center used 3 percent of total power consumption in U.S. It may reach above 15 percent in the future [3]. The explosive expansion of data centers is also responsible for increasing power consumption and carbon footprint. The greatest challenge, global warming caused by green-house gasses like CO2 emission. The statics shows that more than 1.5 percent of the global electricity usage came from data centers in 2011 [4]. The continuous increase in energy consumption of data center causing restriction on the sustainable growth of cloud services and raised environmental and economic concerns.

High-performance computation needs more power. Performance is directly proportional to energy consumption. Excessive heat liberation occurs due to increased rate of power consumption. To maintain low temperature in the data center when performance is high, cooling system also demands more energy. Low-temperature maintenance is necessary to assure reliability and to maintain the life of the hardware. Technologies like DVFS-dynamic voltage and frequency scaling technique is used for energy minimization by reducing frequency in processors. Some exceptional cases showed that by reducing the frequency as well as energy, performance is increased.

Cloud computing is evolving continuously to fulfill the increasing demand of computing, allowing customers to purchase a specific set of resources when they need. software as a service (SaaS), platform as a service (PaaS), infrastructure as a service (IaaS) and recent container as a service (CaaS) are the different types of well-known services provided by the cloud systems [5]. Pay-as-you-go model allows customers to scale services on demand. One of recent research shows that if power consumption rate continues to grow, it will cross the hardware cost of the data center infrastructure.

Green cloud computing is a new area which attracted the attention of researchers all over the world. Energy and performance tradeoff need to solve. Minimization of energy may cause a violation of SLA (Service Level Agreement). Violation of SLA causes a penalty to cloud service providers. Due to uncertain workloads and for maintaining performance by providing availability at anywhere, anytime to users is one of prime objective of cloud.

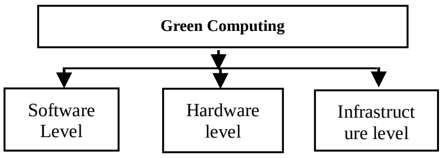

Fig. 1 Green Computing Taxonomy

We divided green computing into three categories. Software level, hardware level, infrastructure level. Each level is dependent on other. But the area where one level is prominent for achieving green computing is categorized in that area. We studied and analyzed current trends, problems and proposed methods by various researchers. We tried our best to deliver brief introduction of green computing and green cloud computing. The new reader will able to understand breadth and depth of the subject and will able to decide sub-area in Green Computing for further research. Electricity dependent infrastructure suffers from idle times or low utilization for some days or months due to offseason caused by nature of random arrivals of requests to servers. Many techniques invented for reducing energy consumption by cloud providers [6]. Primary techniques include virtualization. Virtualization optimizes energy consumption and resource reliability. But there is scope for improvement in different energy saving techniques like energy-aware resource allocation heuristics, ISN, SN, SI policies using green control algorithm, thermal efficient resource management in virtualized data center, bin packing algorithms for virtual machine placement, dynamic allocation based on current utilization of resources [6]. Government of different countries is collecting tax on greenhouse gases like CO2 dissipation from IT industries. Total cost for cloud services is increasing due to inefficient energy utilization. Green computing is an essential research area for industry, environment, and users. Remainder of a paper is structured as follows, introduction section gives a brief overview of problems and methods related to energy in computation. Different methods categories are described for energy optimization. The second section describes different techniques for achieving green computing at the hardware level proposed by various researchers. Peak and Idle situation in hardware, software and in infrastructure level are discussed. Third and fourth section elaborates techniques at software and infrastructure levels in perspective of green computing. Finally, conclusion and future scope are given in the fifth section.

II. GREEN COMPUTING – HARDWARE LEVEL

Green Computing incorporated for solving the problem of increasing carbon footprint and energy optimization. Different authors proposed various solutions to three areas where unnecessary energy consumption can be reduced. We categorized green computing in three main areas. Namely green computing in hardware level, software level, and infrastructure level. Nowadays cloud computing is becoming life and soul of industries as well as all classes of users. Almost more than 50 percent mobile users own smartphones. Android phones became very popular in the world due to its flexibility and usability. Android servers are being hosted in cloud. A cashless economy is being promoted, Online services are being used for flight booking, for banking and up to online shopping of daily needs. More than thousands of apps, websites are being hosted in the cloud. The largest database in the world DNS, which is also expanding as daily many domain names are being purchased, updated. Many organization are migrating their data, applications into clouds. Data centers and computer networks (internet) are the prime backbones of Cloud.

Cloud computing is a new computing paradigm for better performance and ease of use as well as maintenance. Cloud computing utilizes a large number of data centers or server farms. Each data center consists of hundreds or thousands of physical machines arranged in hundreds of racks that can run lacks of virtual machines (VMs). E.g. Google, one of the most famous cloud-based company, delivers all of its services through the cloud, such as Gmail, YouTube etc. To provide anytime access to mail, videos, pictures etc., Data is distributed and stored in huge data centers. The backup of all data is also stored and synchronized at the geographically different data center for the protection of data in emergency situations and natural unpredictable calamities like tsunami, earthquakes etc. Google has at least thirty data centers around the world and more than million servers. Amazon web services uses twenty data centers [7]. Green cloud computing area identified by many researchers for its social importance. We have found two main cases based on the workload of servers: Idle time and Peak time, where energy can be saved for cloud computing data centers. We can minimize energy and at least maintain performance as provided when a good amount of energy is supplied. Computation quality, efficiency, and speed are depending on processors and other hardware components. Processing unit consumes more energy than other hardware components. Energy efficiency by processors is increased over a time as processors upgraded in terms of computation, speed, and energy. Still, more energy optimization needs to be achieved by modifying, upgrading architecture of microprocessors. Carbon footprint is depending on the type of energy source used by data center.

More than 80 percent energy sources are thermal power plants which uses fossil fuel like coal. Different components in computing may use different energy sources [8]. Renewable energy sources produce zero carbon dioxide. But only renewable energy source will not be able to fulfill current need of data centers and total computation. Limitations for renewable energy resources demands more attention from scholars. Intensive computation by processors generates excessive heat. Cooling needs more cost to maintain temperature of data center. and green design of hardware reduces energy consumption.

Different solutions have been proposed by researchers for reducing energy consumption. In table II, we have described analysis of some techniques proposed by various researchers. We have found some conclusions from table 1, We got to know that energy efficiency at hardware level is achieved from designing up to manufacturing and implementation phase of hardware. Use of software level solution to manage hardware resources are necessary. Root level research may bring more energy optimization. Efficient management of hardware energy consumption requires help of programs or software. Providing minimum required energy to machines saves energy, but performance degrades. Supplying max. required energy increases performance but heat liberation and power consumption increases.

A. *Greener PC's in Enterprise*

Research says that Idle time of PCs in enterprises are more than 70 percent, Roughly energy used by new desktop PC is 1.5 W while off, 2.5 W in sleep and 60 W energy use while ON [9]. If we minimized idle time of a PC by putting it into sleep mode or off mode, then total yearly energy saving will be near about 400 kWh. If one enterprise consist of 10,000 such a PCs then energy saving will be 40, 00,000 kWh. [9].

Display power management technologies reduce energy used by the screen, when the user is not present in front of PC or desktop. When the user is not looking at the screen of desktop or laptop, display power management that detects user intent, boost low power operation up to 50 percent and increases energy saving to 13 percent [10]. The author used four states for taking the decision of switching to low power mode (turning off display) and returning to screen on mode. The first state is *Away*-When the user is away from the screen (Desktop and PC having a webcam) and the second state is *Interactive-User* is interacting with a display like typing, clicking. The third state is *Attentive*-The user is looking at the screen without interaction. And the fourth state is *Inattentive*-User is not looking at the display. Webcam helps to detect above four states. Image processing is used for detection. Above Proposed scheme by authors reduces 13 percent energy than of time out based DPM (Display Power management) technique.

B. *Heterogeneous multicore platform energy management*

Heterogeneous Multicore Platform Energy Management is proposed by Efraim Rotem at al. [11] to improve performance and efficiency better than the DVFS technique. H-EARTtH algorithm is proposed for managing and scheduling a heterogeneous processor's optimal point which is energy efficient. Homogeneous and Heterogeneous cores of CPU are used which are fast core as well as slow core. H-EARtH is compared with S-LFM, S-RtH, and F-LFM for energy saving analysis. Up to 44 percent of platform energy is saved by the H-EARtH algorithm.

C. *Physical machine resource management in clouds using auction-based pricing model*

Users in clouds demand bundle of instances of virtual machines (VMs). To manage available resources properly and to increase the profit of company this new strategy is proposed [12]. The true valuation of virtual machine can be done if users don't lie by putting the low price of virtual machine and services in clouds. To avoid this case the strategy-proof mechanism is used. Physical machine resource management problem is formulated. G-PMRM and VCG-PMRM algorithm which is proposed by authors consist of winner determination algorithm. G-PMRM is found to be more efficient for deciding allocation much faster than VCG-PMRM algorithm. The performance of G-PMRM scales with the number of users. A similar approach which is based on price called green power in relay-assisted multi-user network is used by Keshav Singh [13].

D. *Peak situation handling –Hardware level*

Due to dynamic nature of requests peak load arises. As a computation load increases, the demand for resources as well as energy increases. In a peak load, the cooling cost also increases. Mean Time Between Failure (MTBF) decreases where servers are continuously in peak load. Servers with required resources need to add in existing cluster of physical machines. Detection of over utilized host is done by the upper threshold on CPU, Network, and RAM. Once over utilized hosts are detected virtual machines should be migrated to another available physical machine (in the case of virtualization) for which required resources are available. If virtualization is not present then remote physical machines with required resources or remote resources can be used in order to fulfill requests of users. Data center networks should have the provision of optional different routes in case of failure of one route. Also, traffic can be distributed divided among different routes in case of peak time. Storage as a service (SaaS) needs more bandwidth as uploading and downloading of content from a user is high in peak time. The threshold on network in such cases helps for identifying the over utilized network and machines. Energy consumption of a network increases abruptly as utilization of network increase in peak time.

When virtualization is deployed in data center peak situation can be handled easily at a software level by deconsolidating virtual machine. But problem is more complex when virtualization is not deployed. The failure rate of resources increases in continuous peak time. This results in degraded performance and violation of SLA. Prevention to peak load is better option to avoid loss in peak load. Double threshold-based policies are helpful to identifying the peak times. Prediction based adaptive models are much helpful. Detection and analysis of the rate of arrival of requests for particular services and a particular type of virtual machines give an idea of peak load. Time of country of users, events, application types, internet service providers for users etc. are some of the crucial issues that lead towards peak load.

Priority based request processing is one of the effective solutions in case of peak load. In peak load, it is very difficult to add and configure more resources. Priority based discrimination of requests helps minimize losses at peak time. Regular hardware maintenance, replacement of old hard disk, regular back of data, maintenance of cooling system, critical observation of energy usage graphs by different. It helps to minimize failure chances at peak load.

E. *IDLE situation handling- Hardware level*

Cloud servers in the data centers are only busy 10 to 30 percent time on an average [6]. 70 percent time serves remains idle. Different strategies are used like virtualization. Virtual machines are consolidated into a minimum number of physical machines and empty physical machines are put into lower power state like hibernate, sleep or off.

Yi-Ju Chiang et al. [6] proposed Green algorithm for achieving cost optimization by using three N-Control policies SI, ISN, SN policies. Energy and cost are optimized using those strategies. Switching physical machine into sleep, off, and idle mode frequently needs more energy and also performance is also affected. N-Control policy limits more switching.

TABLE I

VARIOUS TECHNIQUES PROPOSED BY RESEARCHERS FOR ACHIEVING ENERGY OPTIMIZATION AT THE HARDWARE LEVEL

Sr. No	Year	Authors	Technique	Analysis
1.	2009	B. Nordman and L. Berkeley	Greener PCs for the Enterprise	Identified Idle machine problem, Proposed techniques like Wake-up On LAN for reduction of energy for single machine in Enterprise. Switching between low power modes to high power mode consumes more energy. Switching between modes may overcome energy cost of putting in low power mode. New policies need for Switching.
2.	2011	J. M. Kim, M. Kim, J. Kong, H. B. Jang, and S. W. Chung	Display Power Management That Detects User Intent [10]	Energy wastage due to monitors, display screens of laptop minimized (inattentive user), Image processing used for states detection of the user. Image processing accuracy problems.
3.	2014	Efraim Rotem and et al.	H-EARtH: Heterogeneous Multicore Platform [11]	Efficient use of different cores, Achieved more efficiency than DFVS, optimizes CPU platform energy. Use of heterogeneous CPU is complex than homogeneous CPU
4.	2012	A. Beloglazov, J. Abawajy, and R. Buyya	Temperature Threshold based detection of over utilized Host [14]	Avoids the hardware wear out, keeps host in safe condition.
5.	2005	Kostas Zotos and et al.	Energy complexity of software in embedded systems.[15]	Proposed term energy complexity for embedded system, experiment results shows minimized energy consumption for program of matrix multiplication than estimated energy consumption Generalized technique for estimating energy complexity of algorithm need to be developed, like energy complexity for same platform dependent algorithms
6.	2016	Toolika Ghose, Vinod Namboodiri and Ravi Pendse	Thin is green: leveraging the thin-client paradigm for sustainable mobile computing [16]	Proposed techniques for increasing life of Thin clients, and reduction of energy consumption by thin clients, performance increase in thin clients by 57 % compared to self-reliant devices, poor network infrastructure or low bandwidth will lower down the performance of thin clients.

F. Near-Threshold Voltage (NTV) design for Green Computing

Surhud Khare and Shailendra Jain [17] proposed NTV technology Intel's IA-32 processor. Benefits of NTV and new technologies that harness the green computing. As voltage supply is reduced for processors, power consumption also reduces at a faster rate compared to maximum-frequency time. Energy efficiency improves up to Near-Threshold supply Voltage (NTV), Energy efficiency drops below NTV due to exponential performance degradation. Achieving reliability is difficult when the processor is operating in the ultra-low voltage region. It is proved that near threshold computing has potential to achieve more energy efficiency in silicon systems.

G. Clustering of physical machines

In peak load, Resource demands may increase within a few milliseconds. In data center database servers, SAN, Processing server machines are differently located. When a new machine is added to network it is assigned to a cluster of the physical machines. It is easy in clustering environment to processing request even at peak load using cluster resources.

H. Reduction of networking energy

It is also an principal part of computing where energy is consumed considerably. Routers, Switches, Bridges and various many network components require energy. Green communication is growing research area as a part of green computing. It is proved that emission reduction approaches based on information theory are impractical, authors suggested that minimizing carbon emission and minimizing energy consumption are two different area [8]. Energy sources are not always responsible for carbon footprint. The combination of different energy sources can be used using weighted graph. Routing algorithm uses minimum greenhouse gases emission. proposed new energy efficient model for in wireless storage area network is proposed by Edwin Fernandez and M.S. Vasanthi [18].

I. Using thin client

Thin client architecture for mobile computing is proposed by Edwin Fernandas and M.S. Vasanthi [18]. A major part of computing will be done on server side. Authors proved that total energy used by the thin model is less than total energy used by the traditional model. For a thin client, the model device needs to be always connected to the internet. Network dependency increases in thin client model. Energy efficiency is observed in a thin client. Maintenance cost of thin client devices is low compared to the thick client devices. Centralized processing in the network, centralized databases are some of the areas which are having a similar application like a thin client. Scope for more advancement lies in computer networking and performance and energy efficient request processing by servers.

Virtual desktop infrastructure for a higher education institution, as a green computing aspect proposed by S. Agarwal, R. Biswas, and S. Xavier [19]. Authors also minimize E-waste using this infrastructure. Thin client approach for mobile devices is proposed by Toolika Ghose, Vinod Namboodiri and Ravi Pendse [16] which showed 57 % increment in performance than old traditional self-reliant devices. Computer allocation for use in offices, colleges or government Institutions, if done on the basis of user's requirement and to fulfill the purpose of the machine, will be beneficial to save energy. Laptops are more energy efficient than desktop, But average life of a laptop is less as compared to desktop. Cooling facilities increase the life of a machine. Regular maintenance of internal cooling system components laptops and desktops also cause change in energy consumption. Servicing of personal computing devices is always better. E-waste minimization is another aspect of achieving green computing as many natural resources are being used, while manufacturing of hardware. Green house gases liberation, pollution at the time of manufacturing cannot be avoided from consideration. Proper recycling of hardware components is essential in terms of carbon footprint and environmental concerns.

J. Temperature based threshold for detection of over utilized host

Virtual machines are consolidated into a physical machine for energy reduction. Minimized number of physical machine gets into peak situation as requests of users to respective virtual machines increases and demands of resources are increased. Temperature sensors monitors the temperature of processors. If temperature crosses the threshold [17], it confirms that physical machine is being over utilized. And corresponding repair mechanism is invoked to keep machine safe and reliable. Virtual machine deconsolidation is beneficial in peak load.

Usage of CPU, RAM, and network are monitored continuously or in specific time intervals. If VM are found

K. Threshold-based approach

Crossing upper threshold for a certain amount of time, then the machine is assumed to be in peak condition. For avoiding violation of SLA [14], virtual machine migration is required. Defining threshold for the particular type of a physical machine is depending upon the average utilization of resources like CPU, Network, and RAM. Lower threshold helps in detection of the underutilized host. Experiments have been conducted to find the optimal value of temperature based threshold to avoid overutilization as well as excessive heating of hardware. SaaS needs threshold on the bandwidth of the network due to excessive use of bandwidth. CPU based threshold has two types. Lower threshold value and the upper threshold value. When current CPU utilization goes below the lower threshold value then the host is called underutilized host. When utilization of CPU crosses the upper threshold is called over utilized host. When the host is underutilized then actions have to be taken in such a way that host should switch to low power modes like sleep. If the host is overutilized, then a load of the host should be transferred to another host where resources are available to fulfill the need. This is termed as load balancing method.

L. Dynamic voltage and frequency scaling

As processors frequency is minimized, energy consumption is reduced. But processing time increases. Performance is lowered and energy consumption reduces. Nowadays in mobiles also the option of power saving mode or ultra power saving mode is provided. Voltage is dropped across circuits.

III. GREEN COMPUTING – SOFTWARE LEVEL

TABLE II

VARIOUS TECHNIQUES PROPOSED BY RESEARCHERS FOR ACHIEVING ENERGY OPTIMIZATION AT THE SOFTWARE LEVEL

Sr. No.	Year	Authors	Technique	Analysis
1.	2012	Kocaoglu M, Malak D, Akan OB	Virtual Machine Consolidation[7]	Energy optimization Poor performance when load increased, Overutilization of resources
2.	2012	A. Beloglazov, J. Abawajy, and R. Buyya	Dynamic Virtual Machine Migration in peak load[14]	Based on current allocation of resources Overhead on network due to increased migrations of virtual machines
3.	2012	A. Beloglazov, J. Abawajy, and R. Buyya	Temperature Threshold based detection of over utilized Host[14]	Avoids the hardware wear out, keeps host in safe condition,
4.	2012	A. Beloglazov, J. Abawajy, and R. Buyya	Double threshold policy including Minimization of Migration Algorithm (MM)	Average CPU utilization is max achieved by selecting VM for migration such that after migration of CPU, current utilization of CPU is kept near upper threshold value. Selection of VM for migration in peak time is not minimizing the migration. CPU efficiency is kept good, but migrations are more.
5.	2013	K. Chen, Y. Xu, K. Xi, and H. J. Chao	Intelligent Virtual Machine placement for cost Efficiency in Geo-Distributed Cloud system[7]	Minimized operating cost , Communication cost, energy cost Requires costly infrastructure and maintenance cost , communication cost is more
6.	2015	Y. Chiang, S. Member, and Y. Ouyang	Green Control Algorithm[6]	Optimized energy saving, reduced SLA violation Only best for idle times, Need to change the method in peak load.
7.	2016	V. R. Reguri, S. Kogatam, and M. Moh	Cluster-Based VM Migration [18]	Minimizes network load, and energy used by network Migration of VM clusters overhead is more. Synchronization is needed.

Kirk W. Cameron [1] showed anomaly faster is slower, In some cases minimized frequency of processors executed some task in less time than normal frequency. The most important area where energy can be optimized considerably. The author also showed that minor updates in the operating system and Message Passing Interface (MPI) library changed power profile of a system. Author and team repeated the experiment to nullify human error. Still, the result was same. After isolating the effects of OS and MPI Library, They got an older result. It is proved that software, programming, algorithmic level changes can gain more energy optimization. Above table 2 lists techniques proposed by different types of researchers in achieving green computing at software level. Also we wrote scope of improvement for given techniques. . We found virtualization is most prominent, popular technique for energy optimization. Virtualization having different sub areas like migration of virtual machine, Consolidation are enhanced by many authors. In our analysis we have found that virtual machine migrations can be further improved for more energy consumption. Each new good research work is evolving for green computing in virtualization. For Idle time problem SN, SI and ISN policies are helpful using virtualization.

A. *Peak situation handling- Software level*

Due to consolidation and of the virtual machine and sudden increase in requests from users, peak situation arises. Detection of peak situation can be done by threshold on temperature or CPU-RAM-Network utilization or requests to the virtual machine as well as the physical machine. Fulfilling demands of resources is difficult in peak situation. Service level agreement SLA violation can cause a penalty to cloud service providers. Virtual machine deconsolidation is necessary if virtualization is applied. In absence of virtualization, resources addition to the data center can help to overcome the peak situation.

B. Virtualization solution and Deconsolidation

For virtual machine deconsolidation some points should be considered like selection of virtual machine, selection of host for migration, selection of migration type like live or offline. Is machine should be migrated many virtual machines be migrated?

By considering above issues, energy optimization keeping performance guarantee will be achieved to maximum limit. Hardware reliability will also be gained. Many algorithms are proposed for finding answers to above questions. Like for VM Placement modified best-fit algorithm, minimization of migration etc. after overutilization of CPU, RAM, and network, virtual machines consolidated.

Its new methodology proposed by Reguri and et al [20]. This method reduces network overload and energy, clustering of VM is done by an algorithm. While placing VM clusters in servers requires following questions arises. Which VM cluster requires more energy? Which host should be selected for VM clusters? Different techniques can be used like cluster of the host, where physical servers are added to host for better performance. The data source for VM can be shared as it reduces the time of migration.

C. *Idle situation handling- Software level*

It is the main area where energy can be reduced up to large extent. Virtualization brought revolution in energy consumption and cost. Many virtual machines runs within the same physical machines. Infrastructure cost, the energy of data center reduced considerably. Each virtual machine is having all properties of a real machine having own OS, RAM, storage, IP address. The hypervisor is used to manage VM. VM can be created, migrated, destroyed as demand from users. Migration of virtual machine from one PM (physical machine) called host to another PM can be done for achieving energy efficiency.

Virtual machine consolidation is a process of migrating virtual machines into less number of PM. Other unused PM can be switched to low power state for energy reduction. Host selection, VM selection is done by using various algorithms. Live migration provides facility to process requests and simultaneously migrating VM to other PM (Host) which may be in the different data center. Downtime is short for live migration than offline migration. Live migration has some limitations. Time of migration is more as compared to offline migration time. It also has a negative impact on the application in VM.

D. Online and Offline algorithm and competitive analysis

Offline algorithms can work only when they have all inputs for the algorithm. While online algorithms work even if all inputs at instance are not available. They have to process piece by piece. Virtual machine migration requires online algorithms. The performance of such online algorithms can be calculated with a comparison of offline algorithms [21], [22]. This comparison is called as competitive analysis of algorithms. We can design new algorithm having optimized energy complexity for both peak as well as idle situation.

Different algorithms which are used in virtual machine consolidations are contradictory in peak time. The VMs experience dynamic workloads, which means that the CPU usage by a VM arbitrarily varies over time. The host is oversubscribed, i.e. if all the VMs request their maximum allowed CPU performance, the total CPU demand will exceed the capacity of the CPU. The increasing resource utilization of the virtual machines creates the need of deconsolidation of virtual machines by selecting proper VM and HOST using online algorithms. The energy consumption by the virtual machines can be measured when they are in peak hours. We can monitor energy uses and change in heat liberation from physical machine to detect over utilized HOST.

E. *Green cloud architecture*

The Green cloud architecture proposed by Anton and Buyya [15], is depicted with the high-level design. This design is basically demonstrating the physical machines, virtual machines, green service allocator and consumers who are accessing the cloud computing. The consumer interface is very particular about the pricing, consumer profiler, service analyzer, green negotiator. The green service allocator is rich with energy monitor, service scheduler, virtual machine manager, accounting sections. These sections are vital sections for maintaining the cloud interface with the users of the cloud computing. The cloud computer architecture is rich with several physical services and supported by dedicated virtual machines. The energy consumption is monitored and managed by the energy monitors. The operations of the physical machines and dedicated virtual machines are scheduled by the service schedulers. The virtual manager operations are maintained and managed by the VM Manager. The physical servers stress can be removed and managed by the dedicated virtual machines support. The dynamic power management is controlled by the VM manager to allocate the appropriate virtual machine to the physical server operations.

F. *Energy saving policies N-control policies*

Chiang at al. [6] proposed a very good model for idle time case. Hosts (physical machines) are applied three states busy, idle, sleep. N control policy proposed by Yadin and Naor is used. ISN Policy: Idle to sleep mode. To avoid switching too often and increasing SLA performance this policy is designed. It consists three modes {Busy, Idle, Sleep}. When the machine gets powered on, the requirement is more. The server remains in sleep mode if a number of jobs arrived are less than N value. Other energy Author developed more two policies with slight changes are SN and SI Policies which only holds two modes {Busy, sleep}. The system immediately switches into sleep mode after it becomes empty. The green control algorithm is used to decide the best policy for energy and cost optimization. After experimental evaluation, it shows SI policy can significantly improve the response time of servers when arrival rate of requests is low. Other energy Saving policies are developed on the basis of virtual machine idle time and peak time situations the following Table no. 3 illustrates the merits and scope of improvement of the energy saving policies by keeping the machine as an idle time [23] .

G. *Migration effect on Network*

Migration of virtual machines is essential in consolidation and deconsolidation. Consolidation is done for purpose of energy reduction by putting the idle physical machine into low power state. Deconsolidation process starts after consolidation process. The case for deconsolidation is when the resource request by some or all virtual machine residing in HOST increases and crosses the available resources. That results in failure in the fulfillment of requests of client or delay in fulfilling the request. Performance is sure to go down in such peak load. A number of migrations in deconsolidation.

Also puts pressure on the network as it uses network bandwidth. Sometimes destined host for migration can be present in another network or geographically another location, In such cases, VM performance degrades

A. *Data center design*

Excessive heat dissipation in a data center is one of the important problems. Many energy efficient data center approaches have been defined. Some are wireless sensor based cooling mechanism for finding a hotspot. Rack servers are compact in design. Cold water tube used for cooling. The geographically cold location is preferred for construction of data center. But a communication and maintenance cost increases. Working in data center environment for any person is quite difficult due to low temperature. Data centers are facing many challenges for adopting energy minimization. Old data centers have to upgrade hardware, software, and infrastructure which is very costly. Gradual energy efficient adaptation is time-consuming.

Power Usage Effectiveness (PUE) rating is the main factor for comparison of power lost in distribution, conversion and in the cooling system in data center [24]. PUE is calculated as the ratio of the total power consumption in a data center to the total IT equipment power consumption. The inverse of PUE is called as data center infrastructure efficiency. PUE metric has been decreasing over last decades due to improvement in energy efficient hardware upgradation. In 2003, Typical data center metric was near about 2.6 [24]. In 2010, Koomey estimated average PUE between 1.83 and 1.92. Recent data centers by Google, Facebook and Microsoft was reduced PUEs below 1.1. EPA (Environmental Protection Agency) decided PUE metric as a base for deriving ranking. In Table 3, we listed some of important techniques for achieving green computing at Infrastructure level. Analysis of techniques as given in the table gives idea about current techniques. Data center Energy Efficiency Metric (DCEE) is a more accurate metric which focuses on the actual amount of power estimation used by the IT resources perform a useful task.

IV. GREEN COMPUTING – INFRASTRUCTURE LEVEL

TABLE III

VARIOUS TECHNIQUES PROPOSED BY RESEARCHERS FOR ACHIEVING ENERGY OPTIMIZATION AT THE INFRASTRUCTURE LEVEL

Sr. No	Year	Authors	Technique	Analysis
1.	2012	Massoud Pedram	Energy-Efficient data centers [24]	An elaborate description of achieving energy efficiency in data center. Also, resource provisioning and power and thermal management problems in data centers are introduced. New methodologies and simulation infrastructure needed to achieve green data centers.
2.	2015	Dan Li, Yunfei Shang, Wu He, and Congjie Chen	EXR: Greening Data Center Network with Software Defined Exclusive Routing [4]	Software Defines Routing shown energy reduction of network than Fair Sharing Routing, More flow Scheduling algorithm required to evolve energy efficient network infrastructure
3.	2012	A. Beloglazov, J. Abawajy, and R. Buyya	Dynamic virtual machine migration in peak load[14]	Very good Technique, Based on current allocation of resources, Overhead on network may occur to increased migrations of virtual machines.
4.	2012	A. Beloglazov, J. Abawajy, and R. Buyya	Temperature Threshold based detection of over utilized Host[14]	Avoids the hardware wear out, Keeps host in safe condition.
5.	2013	K. Chen, Y. Xu, K. Xi, and H. J. Chao	Intelligent Virtual Machine placement for cost Efficiency in Geo-Distributed Cloud system[7]	Minimized operating cost, communication cost, energy cost, but requires costly infrastructure and maintenance cost, communication cost is more
6.	2015	C. Cheng, S. Member, S. Tsao, and P. Lin	SEEDS Solar-based energy efficient Server farm[22]	Reduction in carbon footprint, effective utilization of renewable energy source Costly setup, insufficient generation of power , depends upon seasons
7.	2017	K. Kim, F. Yang, V. M. Zavala, and A. A. Chien	Data Centers as Dispatchable Loads to Harness Stranded Power [28]	Spillage and average power cost decreased dramatically Identification of impacts of load constraints requires for practical implementation.

$$DECC = ITU \times ITE / PUE$$

Where IT Utilization-ITU is the ratio of average use of IT peak capacity of IT in the data enter, and IT Efficiency-ITE is the useful IT work done amount per joule of energy. ITU varies in a period of twenty-four hours. The function of the number, types of active servers and their utilization levels is ITE.

Infrastructure decides many factors like scalability, quality, energy efficiency. Data center infrastructure determines the energy consumption. Cooling systems, network infrastructure are main areas where energy consumption affects. Model to use solar energy for distributed server farm is discussed by Chien-Ming Cheng et al [25]. Integrated approach to data center power management is proposed by Lakshmi Ganesh et al. [2]. Author integrated two approaches, power proportional approach which focuses on server farm consumption as well as minimizing disk utilization, second is green data center approach which points out minimizing power consumed by support infrastructure of data centers like cooling system, power distribution units, and power backup system. Power down of idle racks, containers and servers are required keeping performance unaffected.

B. Peak situation handling-Infrastructure level

Energy consumed at peak level is very high. Heat dissipation from the processors also increases in peak situation. The cooling system should be attentive to note sudden or gradual temperature rise in data center. High temperature can cause system failures, which can lead to financial loss. Data center design approaches need to should consider those facts. Many researchers proposed useful data center design approaches.

Minu bala and Devanand [24] evaluated the performance of data centers in perspective of green computing. Xiang Deng et al. [26] proposed eco-aware online power management and load scheduling method using renewable energy sources. Authors tried to minimize eco-aware power cost of cloud data center keeping a good quality of experience (QoE). The problem was formulated as optimization problem called constrained stochastic problem. They applied Lyapunov optimization theory to design online control algorithm.

Sonika P Reddy et al. [27] proposed energy-aware scheduling of non-real time and real time task on cloud processors. In peak hours, priority based discrimination helps for processing request keeping performance . Discrimination of requests based on users is necessary for peak hours. Many cloud companies started providing services into three categories based on priority and quality of services. Platinum, Gold, Silver and Bronze are categories of service in descending order of their quality of services, Performance respectively. Cost are also in decreasing order. The energy requirement for by Platinum and Gold are high due to assure the quality of services.

Lena Mashayekhy et al. [12] addressed the problem of physical machine resource management in cloud data center. For different types of PM and resources. Using auction based setting and design strategy which is optimal, the problem was formulated. Winner determination algorithm was used for selecting users, provisions of VM to PM, allocation of selected users and payment function for determining the amount for each selected users to pay to the cloud provider. Similar kind of application is an Indian railway premium tatkal scheme. Where the cost of the seat is more than general, and tatkal seats depending upon demand and availability of seats. Online algorithms are compulsory for auctions. The online algorithm should be verified by competitive analysis with similar offline algorithms.[28]

Guohui Wang T. S. Eugene Ng [29] analyzed the impact of virtualization on network performance of Amazon EC2 data center. Virtualization is proven a solution for energy optimization, but still more upgradation in algorithms for VM consolidation and deconsolidations are required. Fahimeh Farahnakian et al. [30] proposed nature inspired ant colony system to consolidate VM are proposed. But the probability of peak situation arising is increased as the consolidation occurs. Similar energy and performance aware policies for deconsolidation are required.

C. Idle situation handling-Infrastructure level

Idle servers at data centers cause energy wastage and inefficient resource management. 70 percent of machines are found to be idle. For only providing the best performance to users energy wastage is neglected. In starting phase of cloud it was not a noticeable thing, but as numbers of internet users are increasing, Cloud services are becoming popular. Number and scaling of all data centers increased. Now all governments, environment protectors caring for reducing carbon emission and power reduction.

Nowadays, like government of different countries, current Prime Minister of India, also promoting cashless economy for better governance. Today's scenario shows that a number of data center and cloud services are surely growing. Efficient resource management can solve the cost of data centers. Data center location, design approach, network infrastructure, cooling system, virtualization are different things for energy and performance efficient data centers for counteracting idle situation and peak situation.

D. Achieving Green Computing for different types of workloads.

There are three main types of workloads computation intensive workload, Data intensive workload and hybrid workloads which contain both types of workloads. Computational intensive workload such as graphics processing, scientific calculation etc. creates more load on processors of data centers. Data intensive workloads are from online storage services like cloud storage service. High bandwidth is being used by data intensive workloads as many downloading and uploading of data happens. In peak time, network suffers from data intensive workloads. Problems like bottleneck problem reduces the performance of services.

Hybrid load is from the applications like geographical maps like Google map and systems like GPS where both data need to be transferred in large amount and computation is need to be done. Green policies vary depending on the type of workload in data center. Green networking is helpful for assuring energy optimization in data center. Various techniques are proposed for the character of workload type in data center [31] [32], [33].

Characterization of workload assists to for prediction of energy demand and modeling green policies for data center.

E. Virtualization

We referred topic already in green cloud computing in software level, but virtualization affects infrastructure. Virtualization is of three types- Full Virtualization, Paravirtualization (or OS assisted Virtualization) and Hardware-assisted virtualization [34]. Full virtualization provides abstraction from hardware and provides right for the creation of complete VM. Paravirtualization is having guest OS, which runs above Paravirtual machines. It requires modification in Guest OS. The advantage is that it reduces virtualization overhead over Full Virtualization. But demerit is performance is low and requires more maintenance. Xen project is an example of Paravirtualization. Hardware-assisted virtualization reduces the need of binary translation because of modified hardware for virtualization. (VT-x) and AMD-V came with hardware for virtualization. Performance is best in hardware-assisted virtualization. The hypervisor is virtual machine monitor. VMware Inc. is the main organization to offer business virtualization. It offers VMware vSphere (in the past VMware Infrastructure no. 4) for PC equipment virtualization that incorporates VMware ESX and ESXi hypervisors that virtualize the underlying hardware. VMware vSphere likewise incorporates vCenter Server that gives a brought together indicate administration and design of IT re-sources, VMotion for live moving VMs, and VMFS that gives a high-performance file system using clusters. Full Virtualization and Paravirtualization is supported by VMware. Likewise, Xen server and KVM also supports for Virtualization.

The carbon emission rate is calculated kg per Kilo watt hour. Every data center causing for increase in greenhouse gases. One Google search generates 0.02 gm. of CO_2, The power consumption techniques of CO_2 which requires 0.0003 KW-h/1kJ. All monthly Google search generates as much CO_2 as human breathe in 824 years. Infrastructure level green computing solved the problem upto some extent.

Table III, Shows analysis of different techniques. It shows areas like network, Energy efficient datacenters like SEEDs , design, location respective to users, virtualization techniques, energy efficient cooling system,minimizing Datacenter PUE value by reducing energy leakage, Carbon footprint of datacenter are some of the predominant issue for procuring green computing.

V. CONCLUSION

Three dimensions for establishing green cloud computing – hardware level, software level, and infrastructure are described in this paper. Peak time and Idle time of workloads are challenges for maintaining reliability, performance, energy optimization of the data center.

Accomplishing green computing at hardware level is an important dimension. Energy efficient processor design, use of DVFS, H-EARtH for efficient use of different cores for energy reduction, heat dissipation reduction by processors, use of threshold on CPU or temperature threshold to detect problems with hardware components for maintaining reliability and increase their life. Manufacturing processes of computing hardware is also caused the problem of pollution and greenhouse gasses. E-Waste management and green recycling of old, usable hardware are also part of green computing. Hardware level techniques for achieving green computing may vary according to unique hardware characteristic. Thinking at the root level of hardware for achieving green computing is the best way to proceed one may find that little reduction of energy will not affect much. But such reduction in millions of server makes the different. More attention at the level of hardware is needed to achieve the green computing.

Achieving green computing at software level shows highest results than at hardware level and infrastructure level. Virtualization is a big area and can be treated as a separate subject for green computing which we categorized under software level green computing. Virtualization proved by reducing energy of cloud services and data center by reducing the idle time energy wastage. Using energy efficient algorithms, analyzing the performance of the algorithm in terms of energy complexity is needed. Power management schemes using software, using energy efficient OS for servers, energy efficient routing in a network using distributed bandwidth are some of the examples for achieving green computing.

The infrastructure of computing environment or data center infrastructure needs to be green. architecture, design, network infrastructure, power schemes, energy sources for data center, scalability of data center for adding new machines, hardware up gradation strategies, cooling system like cold water tube cooling mechanism, sensor-based cooling system for maintaining temperature in all part of data center, maintenance Policies are some of the important attributes of Infrastructure for achieving green computing. Moving data closer to the user, SEEDs solar based energy efficient server farm are some useful solutions provided by researchers. Data center is one of the important backbones of cloud computing. Sustainable data center design, architecture, hardware resources and energy resources need to promote. Industries will be inspired to adopt green computing strategies when these green strategies will lead to enhancing profit. New data centers to design and architecture should be scalable in terms of energy efficiency. PUE value should be low for data centers. Software solutions like virtualization are very much effective in terms of green computing. Infrastructure replacement is costly for old data centers to adopt green computing and energy demand.

There are many untouched areas where green computing can be achieved. Renewable energy Sources needs more attention from researchers. Carbon footprint is zero when energy is supplied by renewable energy sources. Mixed approach of using energy efficient hardware and software can reduce energy consumption and achieve green computing to large extent. Idleness problems have been solved with the help of virtualization (or virtual machine consolidation using migration techniques) to the great degree. But, when virtual machines resource demand increases, artificial peak load arises. That leads to increased virtual machine migrations, which consumes more energy and puts a load on the network, which results in degradation of performance. The migrations should be less in number keeping energy efficiency high. Virtual machine migrations policies vary according to the purpose of migration. In green computing, Energy efficient virtual machine migration needed. There is need of more efficient online algorithms and techniques for optimization of current virtual machines consolidation, Nature-inspired algorithms may help for virtual machine for allocation, migration and efficient consolidation purpose. Virtual machine migration algorithms need to be improved especially in peak times. Energy and performance efficient resource management, efficient the infrastructure of the data center are some future directions where more energy and performance optimization can be done. Solving optimization problem of energy consumption and performance of computational services is a challenge in front of researchers.

VI. REFERENCES

[1] K. W. Cameron, "Energy Oddities , Computing Is Odd," 2013.

[2] L. Ganesh, H. Weatherspoon, T. Marian, and K. Birman, "Integrated Approach to Data Center Power Management," vol. 62, no. 6, pp. 1086–1096, 2013.

[3] J. Bi, H. Yuan, W. Tan, and B. H. Li, "TRS: Temporal Request Scheduling with bounded delay assurance in a green cloud data center," 2016.

[4] D. Li, Y. Shang, W. He, and C. Chen, "EXR: Greening Data Center Network with Software Defined Exclusive Routing," *IEEE Trans. Comput.*, vol. 64, no. 9, pp. 2534–2544, 2015.

[5] M. Warnaar, "Cloud Energy Consumption Measurement and Reduction: an Overview of Methods," pp. 1–13, 2016.

[6] Y. Chiang, S. Member, and Y. Ouyang, "An Efficient Green Control Algorithm in Cloud Computing for Cost Optimization," vol. 3, no. 2, pp. 145–155, 2015.

[7] K. Chen, Y. Xu, K. Xi, and H. J. Chao, "Intelligent Virtual Machine Placement for Cost Efficiency in Geo-Distributed Cloud Systems," pp. 3498–3503, 2013.

[8] M. Kocaoglu, D. Malak, and O. B. Akan, "Communications and Computing:," pp. 40–46, 2012.

[9] B. Nordman and L. Berkeley, "Greener PCs for the Enterprise," no. August, 2009.

[10] J. M. Kim, M. Kim, J. Kong, H. B. Jang, and S. W. Chung, "User Intent," pp. 60–66, 2011.

[11] C. F. E. Computing, "H-EARtH: Heterogeneous Multicore Platform."

[12] L. Mashayekhy, S. Member, M. M. Nejad, and S. Member, "in Clouds: A Mechanism Design Approach," vol. 3, no. 3, pp. 247–260, 2015.

[13] K. Singh, S. Member, and M. Ku, "Toward Green Power Allocation in Relay-Assisted Multiuser Networks: A Pricing-Based Approach," vol. 14, no. 5, pp. 2470–2486, 2015.

[14] A. Beloglazov, J. Abawajy, and R. Buyya, "Energy-aware resource allocation heuristics for efficient management of data centers for Cloud computing," *Futur. Gener. Comput. Syst.*, vol. 28, no. 5, pp. 755–768, 2012.

[15] K. Zotos, A. Litke, A. Chatzigeorgiou, S. Nikolaidis, and G. Stephanides, "Energy complexity of software in embedded systems."

[16] T. Ghose, V. Namboodiri, and R. Pendse, "Thin is green: Leveraging the thin-client paradigm for sustainable mobile computing q," *Comput. Electr. Eng.*, vol. 45, no. 2015, pp. 155–168, 2016.

[17] S. Khare, "Prospects of Near-Threshold Voltage Design for Green Computing," 2013.

[18] Y. E. F. M. S. Vasanthi, "Energy Efficient Mechanism for Green Computing in Wireless Storage Area Networks," pp. 1311–1314, 2015.

[19] S. Agarwal, R. Biswas, and S. Xavier, "Virtual Desktop Infrastructure in Higher Education Institution: Energy Efficiency as an application of Green Computing," 2014.

[20] V. R. Reguri, S. Kogatam, and M. Moh, "Energy Efficient Traffic-Aware Virtual Machine Migration in Green Cloud Data Centers," pp. 268–273, 2016.

[21] S. Roy, "An Energy Complexity Model for Algorithms," 2013.

[22] A. Beloglazov and R. Buyya, "Optimal Online Deterministic Algorithms and Adaptive Heuristics for Energy and Performance Efficient Dynamic Consolidation of Virtual Machines in Cloud Data Centers," pp. 1397–1420, 2012.

[23] A. Beloglazov, "Energy-Efficient Management of Virtual Machines in Data Centers for Cloud Computing," no. February, 2013.

[24] Massoud Pedram, A. C. E. Data centers, "Energy-Efficient Data centers," vol. 31, no. 10, pp. 1465–1484, 2012.

[25] C. Cheng, S. Member, S. Tsao, and P. Lin, "SEEDS: A Solar-Based Energy-Efficient Distributed Server Farm," vol. 45, no. 1, pp. 143–156, 2015.

[26] X. Deng, D. Wu, J. Shen, and J. He, "Eco-Aware Online Power Management and Load Scheduling for Green Cloud Data centers," pp. 1–10, 2014.

[27] G. C. Computing, "Real-Time Tasks on Cloud

Processors," no. 978, pp. 1–5, 2014.

[28] S. Albers, "Online Algorithms," pp. 1–22.

[29] G. Wang and T. S. E. Ng, "The Impact of Virtualization on Network Performance of Amazon EC2 Data Center," 2010.

[30] F. Farahnakian, A. Ashraf, and T. Pahikkala, "Using Ant Colony System to Consolidate VMs for Green Cloud Computing," vol. 8, no. 2, pp. 187–198, 2015.

[31] Z. Jia, L. Wang, J. Zhan, L. Zhang, and C. Luo, "Characterizing data analysis workloads in data centers," *Proc. - 2013 IEEE Int. Symp. Workload Charact. IISWC 2013*, pp. 66–76, 2013.

[32] S. Shen, V. Van Beek, and A. Iosup, "Statistical characterization of business-critical workloads hosted in cloud data centers," *Proc. - 2015 IEEE/ACM 15th Int. Symp. Clust. Cloud, Grid Comput. CCGrid 2015*, pp. 465–474, 2015.

[33] D. Gmach, J. Rolia, L. Cherkasova, and A. Kemper, "Workload analysis and demand prediction of enterprise data center applications," *Proc. 2007 IEEE Int. Symp. Workload Charact. IISWC*, pp. 171–180, 2007.

[34] M. H. Ferdaus, M. Murshed, R. N. Calheiros, and R. Buyya, *Network-Aware Virtual Machine Placement and Migration in Cloud Data Centers*. 2015.

Mr. Aniket N Nikam is currently *Assistant Professor* in the Dept of Computer Science & Engg, Shri Guru Gobind Singhji Institute of Engineering and Technology (SGGSIET),Vishnupuri, Nanded, Autonomous Institute of Government of Maharashtra, India. He also worked as Lecturer at the Department of Computer Engineering, Institute of Petrochemical Engineering, Dr. BATU, Lonere. He Completed Masters (M.Tech) with Honors from the ***National Institute of Technical Teachers' Training and Research (NITTTR), Bhopal*** Under guidance of *Dr. Shailendra Singh*. His area of interest include Green Cloud Computing, Database Management System, Machine Learning & Web Engineering.

https://orcid.org/0000-0002-3643-0913

Dr. Shailendra Singh, **Ph.D.** is currently **Professor** in Department of Computer Engineering and Applications at *National Institute of Technical Teachers' Training and Research, Bhopal*. He has more than 20 years of experience in Teaching, Industry and research as well as education and training for human resource and development. Dr. Singh has supervised two Ph.D thesis. He is a member of many professional bodies including senior member of IEEE, USA. His current research interests are Machine learning and Cloud Computing. He has also delivered expert talks and chaired the session in International Conferences in India and abroad. He is a member of editorial board and reviewer of various prestigious journals and conference proceedings. He has organized number of international and national conferences. He has authored 3 books (1 edited) and contributed 2 book Chapters. He has served as Technical Chair IEEE international conferences held in India and abroad. Dr. Singh has published more than 60 research papers in International and National Journals some of the research papers got published in SCI journals and have presented in prestigious International and National Conferences. His research publications have been referred by many researcher in their research work. He has been keenly involved in various consultancy projects.