Weaving Electrical and Computational Grids: How Analogous Are They?

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Abstract:

Inspired by the *electrical power grid's* ability to provide a pervasive access to power in a consistent and dependable manner, computer scientists began exploring the design and development of an *analogous* infrastructure called the *computational power grid* for the 21st century network computing. At present, such computational grids enable sharing, selection, and aggregation of geographically distributed resources for solving large scale problems in science, engineering, and commerce. In order to identify the potential of computational grids' ability to make impact on our economy similar to the electrical grids, it is essential to identify the characteristics of various components, systems and methods along with the salient features and the analogous nature of both these systems. It is hoped that such comparison and contrasting of the features of these technologies and their infrastructures will provide further momentum to improve the current state-of-the-art in computational grids. It will help in identifying what areas need to be further focused upon. In this article, we briefly note historical background, architecture, and technology for the computational power grids; discuss its operational model, policies and establish an analogy with the electrical power grid. We compare and contrast the two grids to identify the way they deal and address management and access issues; and to learn from each other's success and failure.

1. Introduction

With the invention of the electrical battery by Volta in 1800, Edison paved the way for its utilization in the form of invention of the electric bulb. Figure 1 shows Alessandro Volta demonstrating the battery in Paris in 1801 inside the French National Institute while in the presence of Napoleon I [1]. Presuming that Volta had a vision for a worldwide electrical power grid, that vision certainly become a reality with the electrical grid being able to provide dependable, consistent, and pervasive access to power to drive utilities and has thus become an integral part of the modern society. Approximately one and half centuries later, similar developments are being observed in the field of computer networks, distributed computing, and high performance computing. Inspired by the *electrical power grid's* ability to provide pervasive access to power in a consistent and dependable manner for driving utilities, computer scientists in the mid 1990s, began exploring the design and development of a new infrastructure called *computational power grids* for the 21st century network computing [6]. However, unlike electrical grids, computational grids are not born out of basic human needs, but on the needs of scientists who are interested in solving large-scale data and resource intensive applications that need more computing power than that can be provided by a computer (supercomputer or cluster) in a single domain. This need has paved the way for scalable computing from distributed parallel computing with commodity computers (such as PC and workstations) interconnected by local-area networks in a single administrative domain [5], popularly called cluster computing [7], to a distributed parallel computing with high-end computers (such as clusters and supercomputers) interconnected by wide-area networks (such as Internet) in multiple administrative domains. These platforms enable an aggregation of distributed resources for solving problems with large-scale data and compute-intensive processing requirements.

The communication infrastructure of the computational grid is the Internet that began as a modest research network supported by the Advanced Research Projects Agency (ARPA) of the US Defense Department in 1969. The ARPANET was initially intended to be a distributed computing network, but it ended up as a communication infrastructure. However, in the mid 1990s, the availability of high-speed networks such as Gigabit networks as commodity components and the ubiquitous nature of Internet and Web fueled interest among the scientific community to explore aggregation of geographically distributed resources spanning across multiple administrative domains for solving grand challenging problems. At other fronts, projects such as Distributed.net [40] and SETI@Home [41] launched in 1997 and 1999 respectively, attracted world-wide attention and millions of participants from all over the world to contribute idle CPU cycles of their computers, mainly PCs, for processing RSA Labs RC5-32/12/7 (56-bit) secret key challenge and for processing large pulsar signals database aiming to search for extra terrestrial intelligence. This extreme form of computing is popularly called peer-to-peer (P2P) computing [19]. It is also being envisioned that such notion of collaboration among communities to share resources for solving problems will lead to the creation of virtual organizations [18], and virtual enterprises [17] when they organize themselves with computational economy to share resources for solving problems.

Figure 1: Volta demonstrating the battery in the presence of Napoleon I at French National Institute, Paris, 1801.

ajor technological advances in networking and computing leading to the emergence of peer-to-peer networks and computational Grids are shown in figure 2. It can be observed that the research and developmental work for implementation of computational Grids is going on at a very brisk pace and it can be hoped that its performance and ease of use may reach the level of the electrical power grid within a few years. Already application domains, such as Monte Carlo simulations and parameter sweep applications (such as ionization chamber calibration [9], drug design [38], operations research, electronic CAD, and ecological modeling), where large processing problems can easily be divided into sub-problems and solved independently, are taking great advantage of grid computing.. For pointers to a list of major Grid projects around the globe, see [12][26].

This paper is devoted to a brief description of the structure, operational model and advantages of the computational power grid. Moreover, we bring together two physically different systems; namely, the matured electrical power grid and an infant computational power grid and attempt to show the similarities and dissimilarities between the two systems. Further, analogous quantities and parameters of the two grids are also identified. The advantages of such a comparison could be manifold, for example, taking a cue from the electrical power grid, some of the possible areas in the realm of computational grid that need more focus can be identified.

2. Computational Grid

The proliferation of the Internet, Web, and the availability of low-cost high-performance computers are enabling the creation of computational grids [6] for sharing distributed resources. They allow aggregation for geographically distributed high-end computing resources for solving large-scale problems. In this section we will discuss, in more detail, the major technological milestones towards the development of computational grid, its layered structure, operational model of the computational grid, which is envisaged to provide a seamless access computational resources.

2.1. Major Technological Milestones

Compared to the history of the electrical power grid that spans for more than two centuries, the computational grid (rather computer communication infrastructure, the Internet) has a history of less than half a century. Figure 2 shows some of the major breakthroughs that happened from 1960 to date in computing and networking technologies, which is leading to the emergence of service-oriented peer-to-peer (P2P) [19] and grid computing [6]. The advances in technologies have lead to the rise and fall of different systems. In 1960, mainframes mainly from IBM were serving the needs of computing users, but a decade later DEC introduced less expensive minicomputers that took over mainframes market share. During 1980s, vector computers (e.g., Crays) and later parallel computers (e.g., MPP systems) were serving the needs of grand challenging applications.. We discuss the major breakthroughs briefly in the following paragraphs.

The communication infrastructure for computational grids is the Internet that began as a modest research network funded by the Advanced Research Projects Agency (ARPA) of the US Defense Department. The ARPA's effort started as a response to the USSR's launch of Sputnik, the first artificial earth satellite in 1957 [28]. The ARPANET with four nodes was first established in 1969 at the University of California at Los Angeles, Stanford Research Institute, University of California Santa Barbara (UCSB), and University of Utah during September, October, November, and December months respectively. By the mid-1970s, the ARPANET *Internet* work embraced more than 30 universities, military sites and government contractors and its user base expanded to include the larger computer science research community. Bob Metcalfe's Harvard PhD Thesis outlines idea for Ethernet in 1973 that came into existence in 1976 [30]. Vint Cerf and Bob Kahn proposed Transmission Control Program (TCP) in 1974, which is split into TCP/IP in 1978. By 1983, the network still consisted of a network of several hundred computers on only a few local area networks. In 1985, the National Science Foundation (NSF) arranged with ARPA to support a collaboration of supercomputing centers and computer science researchers across the ARPANET. In 1989, responsibility and management for the ARPANET, was officially passed from military interests to the academically oriented NSF. Much of the Internet's etiquette and rules for behavior was established during this time. Internet Engineering Task Force (IETF) was formed during 1986 as a loosely self-organized group of people who contribute to the engineering and evolution of Internet technologies [29].

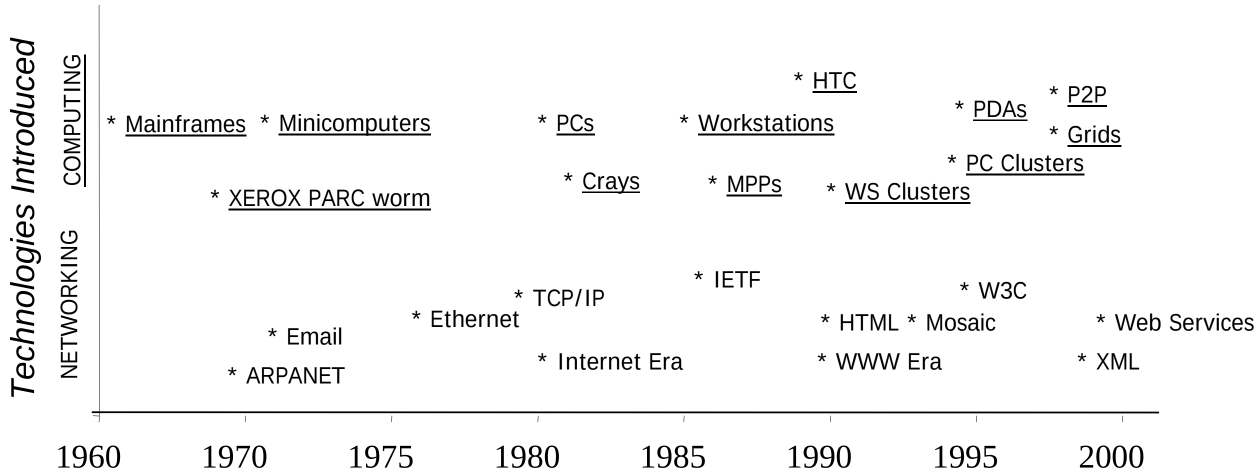

Figure 2: Major milestones in networking and computing technologies from the year 1960 onwards.

The invention of the Web [33] in 1989 by Tim Berners-Lee of CERN, Switzerland, for sharing information with ease has fueled a major revolution in computing. It provided the means for creating and organizing documents (using HTML language) with links and accessing them online transparently, irrespective of their location (using http protocols, browsers, and servers). The World-Wide Web consortium (W3C) [34] formed in 1994 is engaged in developing new standards for information interchange such as XML (eXtended Markup Language) Web services for developing software as a service via Internet.

In the early 1970s when computers were first linked by networks, the idea of harnessing unused CPU cycles was born [8]. A few early experiments with distributed computing-including a pair of programs called ‘Creeper and Reaper’-ran on the Internet's predecessor, the ARPAnet. In 1973, the Xerox Palo Alto Research Center (PARC) installed the first Ethernet network and the first fully-fledged distributed computing effort was underway. Scientists at PARC developed a program called “worm” that routinely cruised about 100 Ethernet-connected computers. They envisioned their worm moving from machine to machine using idle resources for beneficial purposes. The worm would roam throughout the PARC network, replicating itself in each machine's memory. Each worm used idle resources to perform a computation and had the ability to reproduce and transmit clones to other nodes of the network. With the worms, developers distributed graphic images and shared computations for rendering realistic computer graphics.

Since 1990, with the maturation and ubiquity of the Internet and Web technologies along with availability of powerful computers and system area networks as commodity components, distributed computing scaled to a new global level. The availability of powerful PCs and workstations; and high-speed networks (e.g., Gigabit Ethernet) as commodity components has lead to the emergence of clusters [25] serving the needs of high performance computing (HPC) users. The ubiquity of the Internet and Web technologies along with the availability of many low-cost and high-performance commodity clusters within many organizations has prompted the exploration of aggregating distributed resources for solving large scale problems of multi-institutional interest. This lead to the emergence of computational Grids and P2P networks for sharing distributed resources. The grid community is generally focused on aggregation of distributed high-end machines such as clusters whereas P2P community is looking into sharing low-end systems such as PCs connected to the Internet for sharing computing power (e.g., SETI@Home) and contents (e.g., exchange music files via Napster and Gnuetella networks). Given the number of projects and forums [12][26] started all over the world in early 2000, it is clear that the interest in the research, development, and deployment of Grid and P2P computing technologies, tools, and applications is rapidly growing.

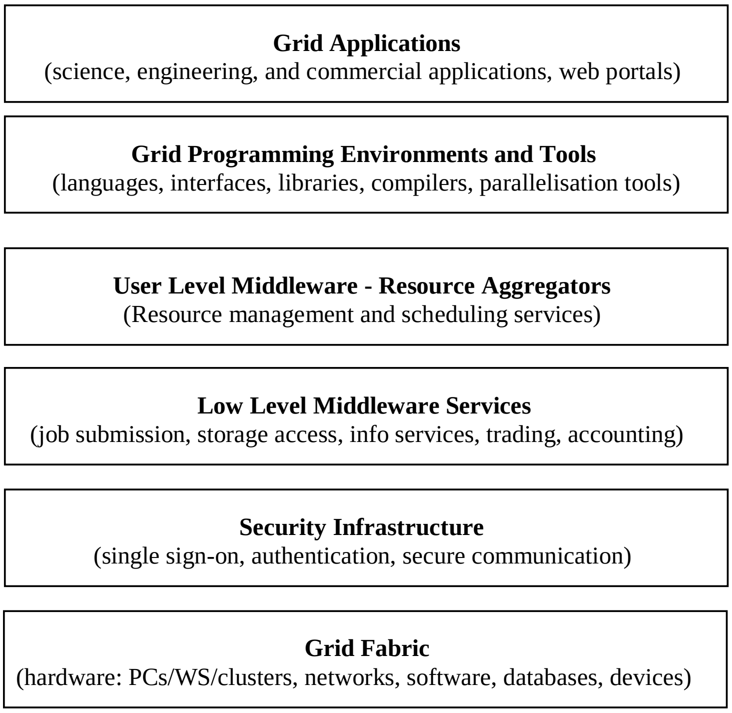

Figure 3: A layered architecture of computational grid and technologies.

2.2. Layered Structure

The computational grid is made up of a number of components from enabling resources to end user applications. A layered architecture of computational grid is shown in Figure 3—discussed in greater depth in [18]. Another comprehensive architecture for the Grid can be seen in [18]. At the bottom of grid stack, we have distributed resources managed by local resource manager with local policy and interconnected through local or wide area networks. Thus the bottom most layer serves as *grid fabric*, which contains computers such as PCs, workstations or SMPs running operating systems such as UNIX or Windows, clusters running various operating systems as well as resource management systems such as LSF (Load Sharing Facility), Condor, PBS (Portable Batch System) or SGE (Sun Grid Engine), storage devices, databases, and special scientific instruments such as a radio telescope or particular heat sensor. A secure and authorized access to grid resources is provided by *security infrastructure*. A layer on top, called *core grid middleware*, offers a uniform and secure access to resources. A security layer can also be implemented as part of core middleware layer. The next two layers form *user-level middleware* consisting of *resource brokers* or schedulers responsible for aggregating resources and *application development tools*. Applications sit at top of the layer and they range from collaborative computing to remote access to scientific instruments to simulations. The grid development tools are used to grid-enable applications and resource brokers manage execution of applications on distributed resources with appropriate scheduling strategies.

2.3. Operational Model

For the operation of a computational grid, the broker discovers resources that the user can access through grid information server(s), negotiates with (grid-enabled) resources or their agents using middleware services, maps tasks to resources (scheduling), stages the application and data for processing (deployment) and finally gathers results [10]. It is also responsible for monitoring application execution progress along with managing changes in the grid infrastructure and resource failures. There are a number of projects worldwide actively exploring the development of various grid computing system components, services, and applications.

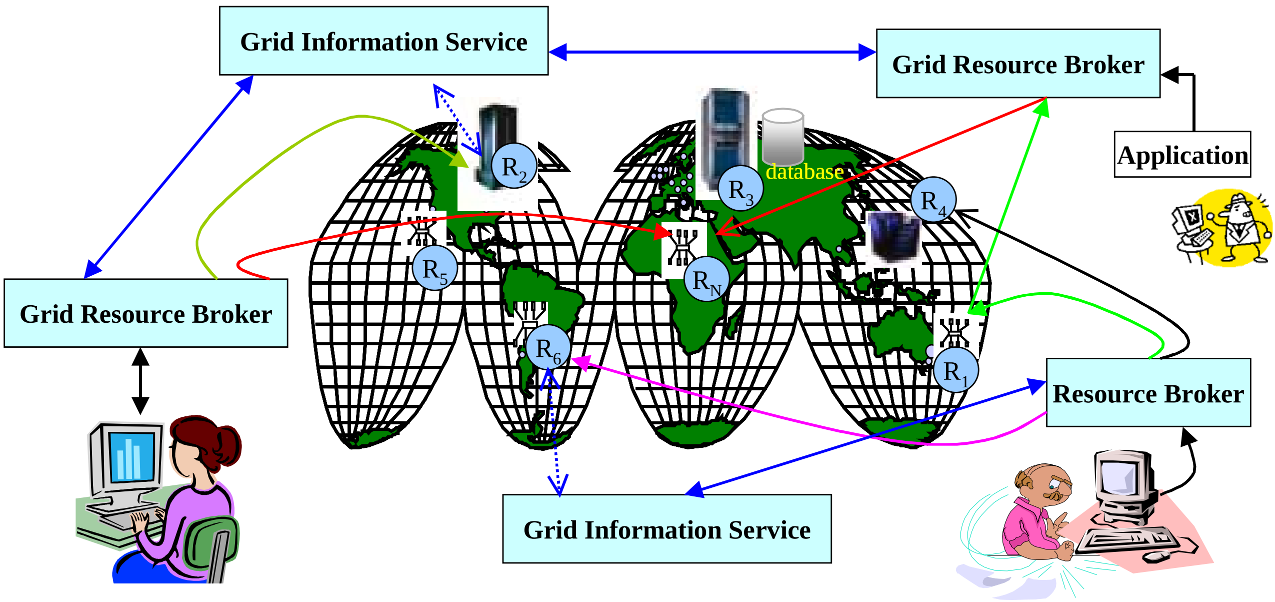

Figure 4: A generic view of computational power grid.

The computing environments comprise heterogeneous resources, fabric management systems (single system image OS, queuing systems, etc.) and policies, and applications (scientific, engineering, and commercial) with varied requirements (CPU, I/O, memory, and/or network intensive). The *producers* (also called resource owners) and *consumers* (who are the users) have different goals, objectives, strategies, and demand patterns [11]. More importantly both resources and end-users are geographically distributed with different time zones. A number of approaches for resource management architectures have been proposed and the prominent ones are: centralized, decentralized, and hierarchical. In managing complexities present in large-scale grid-like systems, traditional approaches are not suitable as they attempt to optimize system-wide measure of performance. Traditional approaches use centralized policies that need complete state information and a common fabric management policy, or decentralized consensus based policy. Due to the complexity in constructing successful grid environments, it is impossible to define an acceptable system-wide performance matrix and common fabric management policy. Therefore, hierarchical and decentralized approaches are suitable for grid resource and operational management [11]. Within these approaches, there exist different economic models for management and regulation of supply-and-demand for resources [17]. The grid resource broker mediates between producers and consumers. The resources are grid enabled by deploying low-level middleware systems on them. The core middleware deployed on producer's grid resources provides ability to handle resource access authorization and permits only authorized users to access them. The user-level and core middleware on consumers' machines provide ability to create grid enabled applications or necessary wrappers for legacy applications for executing on the grid. On authenticating to the grid, consumers interact with resource brokers for executing their application on remote resources. The resource broker takes care of resource discovery, selection, aggregation, data and program transportation, initiating execution on remote machine and gathering results.

2.4. Major Advantages

There are many advantages computational Grids and some of them are listed below: can be very many. Some of these advantages include:

- Enables sharing of resources.
- Transparent access to remote resources.
- On demand aggregation of resources at multiple sites.
- Reduced execution time of large-scale data processing applications.
- It provides access to remote databases and software.
- It helps in taking advantage of time zone and random diversity: Organizations/users who are in peak-time hours can access resources that are in off-peak time as they are likely to be less loaded.
- It provides the flexibility to meet unforeseen emergency demands by renting external resources for a required period instead of owning them

3. Comparison with the electrical power grid

The progress and development in computation technology leading towards computational Grid are similar and analogous to those that occurred in the electrical power grid. For these reasons, since mid 1990s, the present computation operational model is being referred to as an analogous computational power grid Hence, this section is devoted to its comparison with electrical power Grid. The generality with which similarity investigations approach phenomena provides a far-reaching sense and a great perceptual significance[2]. Indeed, the development of physics has confirmed and continues to confirm that many objective processes are subject to general laws, and are therefore described by the similar equations For example, based on similarity relations, a unified mathematical approach can be applied to different branches of science (for example, the same approach to oscillations as to different kinds of waves). Inspired by the significance of similarities, we investigate analogies, similarities, and comparison of computational power grids and the electrical power grid in this section. Such a comparison will enable us to establish that a distinct progress in the direction towards the development of an analogous electrical Grid is happening.

Based on the structure and operating model of the electrical power grid and the analogous computational power grid, some of the analogous elements in these two systems can be easily identified. These analogous elements are presented in Table 1.

Table 1: Electrical vs Computational Power Grids.

Parameter	**Electrical Power Grid**	**Computational Power Grid**
Resources	Heterogeneous such as thermal, hydro, wind, solar, nuclear, etc.	Heterogeneous such as PCs, Workstations, clusters, etc. driven by different operating and management systems.
Network	Transmission lines and underground cables. Various sophisticated schemes for line protection.	The Internet is carrier for connecting distributed resources, load, etc.
Analogous Quantities	Bus Energy transmission	Node Compute transmission

	Voltage Bulk transmission system (230 kV-760 kV) Subtransmission (25kV- 150kV) Distribution (120/240V, 25 kV) Cable Energy (MW-hour) Only small storage capacity in the form of DC batteries	Bandwidth Bulk transmission is by Fibre optic-OC48, ATM (2.4 Gbits per sec) EtherNet, T-3 (45 Mbits per sec) Modem, ISDN etc (56-128 Kbits per sec) Cable Computational power (MFlops) Any magnitude of storage (Megabytes)
Power source	Power station (e.g. turbogenerators, hydrogenerators), windmill	Grid Resource (e.g., computers, data sources, web services, databases)
Load type (based on type of utilisation)	Heterogeneous applications devices, e.g. fan (utilising mechanical energy), TV(electricity), iron (heat)	Heterogeneous applications, e.g. Multi-media (Graphics), scientific/ engineering (problem solving)
Operating Frequency	Uniform elect. freq. Either 50 or 60 Hz. (However, DC systems also exist), Analog quantity, and sinusoidal.	Non-uniform, depends on computer processing power and clock speed Digital and square wave.
Access Interface	Direct access, e.g. via Wall Socket for small consumers or via transformer for industrial consumers.	Uniform interface to different resources is supported (e.g., Globus GRAM interface for submitting jobs to resources [14]).
Ease of Use	Very simple: plug and play!	Very complex, but this is expected to change as computing portals and network enabled solvers [27] are emerging.
Matching device for varying power levels (voltage, bandwidth, CPU speed)	Transformer--changes voltage levels to match e.g. a device (say of 25 Volt) with the supply (say 220 Volt).	Resource brokers do selection of resources that meet users requirements such as quality and cost. Note that applications can run on machines with different capabilities. If a given application can run a machine, it can run on another machine even if that has different operating frequency. That means devices like transformers are not required.
Aggregation of Resources	When a load requires more power than that can be provided locally, additional power is provided via grid. Economic Dispatch Centre uses sophisticated scheduling algorithms and load flow studies that provide the mechanisms to carry out this action.	When an application needs more computational power than that can be provided by a singe resource for faster execution, computational grids allow resource aggregation for executing application components in parallel. The Grid resource brokers such as Nimrod-G [10] provide resource aggregation capability.
Reliability	Important lines are duplicated. Sophisticated protection schemes for the power stations, transmission lines, equipment etc are in use.	The resources in a grid may fail without notice. Therefore, resource brokers need to handle such failure issues at runtime.
Stability	Stability crucial for keeping the generators in synchronism. Sophisticated control algorithms ensure automated mechanism.	It depends on resource management policy. If resource is a shared resource, then available computing power for a user can vary from time to time.
Transmission capacity	Maximum upper limit for the lines based on thermal limits of the lines.	Upper limit based on bandwidth capability of the carrier.
Security/safety	Fuses, Circuit breakers, etc.	Firewall, public key infrastructure (PKI), and PKI based grid security [15]
Co-generation	“yes”, but optional	“yes”, but optional
Storage	Only storage for low power DC using batteries.	No storage of computational power possible.

Automated accounting	Advanced metering and accounting mechanisms in place.	Local resource management systems support accounting. Resource brokers can also account for resource consumption (e.g., Nimrod-G agent does application level metering) and global level service exchange and accounting mechanisms such as GridBank [13] is required.
Interconnection of power system	Various regional power pools (see sec. 3.6) are interconnected by weak connections called as *tie-lines.*	Internet provides connectivity service and tools such as JobQueue in Legion [37] and Condor-G [36] can provide federation resources with tight coupling.
Unregulated Grid operation	Successful operation in countries with sufficient generation capacity (also see sec 3.4).	As this technology matures and businesses start taking advantage, we believe this will come into picture.
Regulated Grid Operation	A load dispatch centre manages optimal system operation [3].(also see sec 3.4)	There is greater potential to use market-based pricing mechanisms to help regulate supply-and-demand for resources [11] [17].
Regulators	In general, managed by autonomous body of vendors and government regulators. For example, NEMMCO [39] in Australia.	At this moment no such body exists, however, we believe the need for a watchdog comes into picture when Grid is moved to mainstream computing. However, some of the supercomputing centers at national level (e.g., in UK [16]) have a facility management committee that decides on token allocation and deciding the value of tokens for CPU time-per-sec., which various for different resources. This resembles price regulation in a single administrative domain, which can be extended to national level with appropriate cooperation and understanding among all such centers.
Standards Body	There are many standardization bodies for various components, devices, system operation, etc. (e.g., IEEE standards on transformers, harmonics etc.).	Already there are forums such as Global Grid Forum [31] and Peer-to-Peer (P2P) WG [32] promoting community practices. The Internet and Web standardization issues are handled by IETF and W3C respectively.

Although most of the parameters listed above are self-explanatory, some of them are examined and discussed in greater detail in the following sections.

3.1 Resources

The modern power grid derives its electricity from the following sources: (a) Coal, gas, oil--70% (b) Hydropower--15% (c) Nuclear-- 15% [4]. Although only to a small magnitude, new prime energy resources such as (a) solar, (b) wind, wave geothermal and tidal powers (3) Photo-voltaic also contribute, to the grid power. Most of fossil-fired powers generating stations are mine-mouth stations i.e. located close to the mines. It can be observed that although the resources in the electrical power grid are heterogeneous, they finally produce an identical output, namely electricity that is exactly identical (i.e. sinusoidal signal at 50 or 60 Hz).

Similar to the electrical grid, which has a wide variety of power resources, the computational grid also has wide varieties of computational resources (such as supercomputers, clusters, and SMPs including low-end systems such as PCs/workstations), which are connected in the grid to provide seamless computing power to the user (load). Apart from these resources, devices for visualization, storage systems and databases, special classes of scientific instruments (such as radio telescopes), computational kernels, and so on are also logically coupled together and presented as a single integrated resource to the user (see Figure 4).

3.2 Network

An electric power system, even the smallest one, constitutes an electric network of vast complexity. However, in any of these systems, the voltage level of a transmission line determines its energy transmission capacity. By increasing the voltage level and physical length of the transmission network, a 'superhighway system' is thus provided for large blocks of electric energy to be transmitted over large distances.

As shown in Figure 5, a typical power network is characterized by the three transmission systems: (a) Transmission (b) Subtransmission (c) Distribution. *Transmission system* handles the largest blocks of power, and also interconnects all the generator stations and all the major loading points in the system. The energy can be routed, generally, in any desired direction on the various links of the transmission system in a way that corresponds to best overall operating economy or to best serve a technical objective. The *subtransmission system* serves a larger geographical area and distributes energy in larger blocks at higher voltage levels. The *distribution system* is mainly the same as that of a subtransmission system except that it constitutes the finest meshes in the overall network and covers the problems of overhead or underground network and distributes power mainly to domestic consumers.

In a computational grid, the resources (and loads) in a computational power grid are connected by Internet using gateways and routers to form a LAN and provide network services such as file transfer, email and document printing to the client computers of that network. A LAN can be further connected to other LANs to form a WAN. The bandwidth (a measure of data handling capacity) of the network is observed to be analogous to the voltage levels (a measure of power handling capacity) of the electric network. Analogous to the transmission system of the electrical grid for bulk power transfer is the Optical Network and ATM connections of the computational grid for large data transfer. Similarly, we have T1, E1 and Ethernet connections, which are analogous to the subtransmission power system, while the modem connections are analogous to the distribution system.

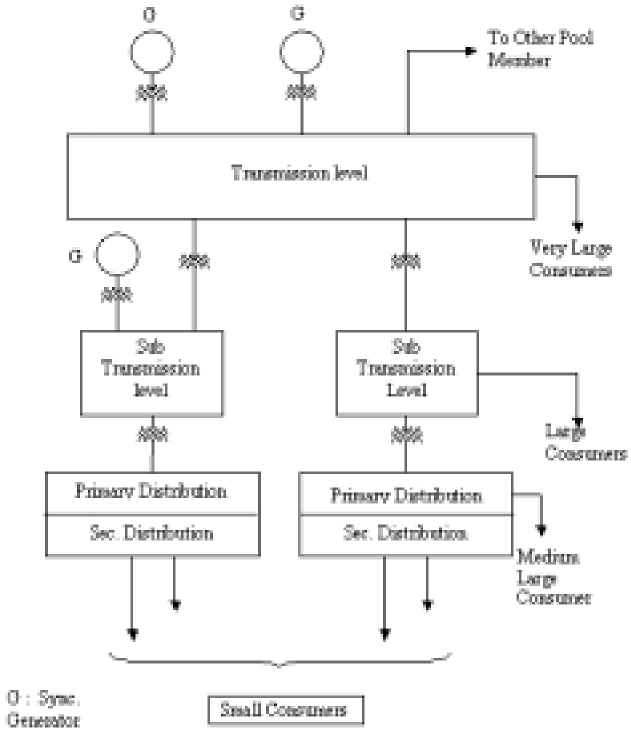

Figure 5: One line diagram of power system.

3.3 System Load

The electric power grid can support various forms of load such as electrical (TV), fan (mechanical), iron (heat) etc. Similar to the heterogeneous load (mechanical, electrical etc.) that can be connected on the electric power grid, the load on the computational grid can also be heterogeneous, which varies with the scope of problem to be solved (e.g., the number of parameters to be explored) and its nature (e.g., I/O or computational intensive). However, a resource broker hides the complexities of aggregating diverse set of resources for solving them. Such an attempt for solving massively parallel problems is very much analogous to the feeding of power to a large electric load from a number of distributed generators in the electrical grid. However, unlike the power grid where the user is unaware as to which of the generators are delivering power to which load, the computational grid provides a clear evidence of the resource(s) where the computations are being carried out.

3.4 Operational Model

The operational model of the computational grid presented in section 2.2 is still growing. Various mechanisms for computational grid operation are in research and development phase [11], [12] whereas, electrical grid well established and ubiquitous. The electrical Grid has been traditionally monopolistic in nature. It has a 'Load Dispatch and Operation Centre' that continually manages the generation requirements in the system based on the load demand. However, since the 1980s much effort has been made to restructure the traditional monopoly of the power industry with the objectives of introducing fair competition and improving economic efficiency. Both of these modes of operation of power grid are briefly presented below and may provide a goal/ benchmark for a future operational model of computational Grid.

Under the regulated power system operation, a common practice is determining the total generation required at any time and how it should be distributed among the various power stations and among the generators within each of these plants. Output of each power station and each of the generating units within the power station is commonly computer controlled for the stable power-system operation. By continually monitoring all plant outputs and the power flowing in interconnections, interchange of power with other systems is controlled. The term *area* means that part of an interconnected system in which one or more companies control their generation to meet all their own load requirements. If this is not possible (due to insufficient generation) then a prearranged net interchange of power with other areas for specified periods is implemented. Monitoring the flow of power on the *tie lines* between areas determines whether a particular area is meeting satisfactorily all the load requirements within its own boundaries. Thus, the function of the automatic system operation is for the area to meet its own load requirements, to provide the agreed net interchange with neighboring areas, to determine the desired generation of each plant in the area for economic dispatch and to cause the area to provide its share. Since the 1980's, much effort has been made to restructure the traditional monopoly power industry leading to unregulated power system operation. The creation of mechanisms for power suppliers and sometimes for large consumers to openly trade electricity is at the core of this change. However, the emergent electricity market is more akin to oligopoly than perfect market competition [20]. This is due to special features of the electricity supply industry such as, a limited number of producers, large investment size (barriers to entry), transmission constraints which isolate consumers from effective reach of many generators, and transmission losses which discourage consumers from purchasing power from distant suppliers. The electricity markets are not perfectly competitive. In recent years, some research has been done in building optimal bidding strategies for competitive generators and/or large consumers, and on investigating the associated market power in which the sealed bid auction and uniform price rule are widely utilized [21]. Broadly speaking, there are mainly three ways for developing optimal bidding strategies. The first one relies on estimations of the Market Clearing Price (MCP) in the next trading period, the second utilises the estimations of bidding behaviour of the rival participants in which techniques such as probability analysis and fuzzy sets, are utilised for estimation [19]. The third approach is to apply some methods or techniques from game theory [22], [23]. Further, many auction methods (e.g. static and dynamic) auctions and bidding protocols (e.g. single-part bid, multipart bidding, iterative bidding, demand side bidding) exist as well [20].

3.5 Dissimilarities in the two Grids

It must, however, be pointed out that that the two Grids under consideration are not completely identical but there are certain aspects of dissimilarities between the two Grids and which need mentioning.. For example, the power system comprises several buses (junction points) or nodes, which are interconnected by transmission line networks. Power is injected into a bus from generators while the loads are tapped from it. At this stage, such an arrangement is not possible in computational grid. Further, apart from the conventional AC transmission, other transmission methods such as High Voltage DC (HVDC) and underground transmission have also been implemented. We do not have an equivalent of this heterogeneous information/data transmission in the computational grid network. Again for economic and technological reasons, most of the electrical systems are interconnected into vast power grids, which are subdivided into regional operating groups called *power pools* [35] as illustrated in Figure 6. Producer A is able to sell power to consumer X to a well-defined price in competition with all the other producers. Each individual power system within such a pool usually operates technically and economically independently, but is contractually tied to the other pool members in respect to certain generation and scheduling features. Although such an operational arrangement does not exist in the analogous computational Grid, we feel that it can be implemented for the computational grid operation when a greater cooperation among participants with flexible policies exist. Some examples of such emerging Grid tools are Condor-G [36] and Legion's JobQueue [37] schedulers. Moreover, in computational Grids, drawing power from the Grid means, push data and/or applications to a resourcethen process it, and subsequently pull results., This is not the situation in electrical power grid where the users can access/pull the power as when they are connected.

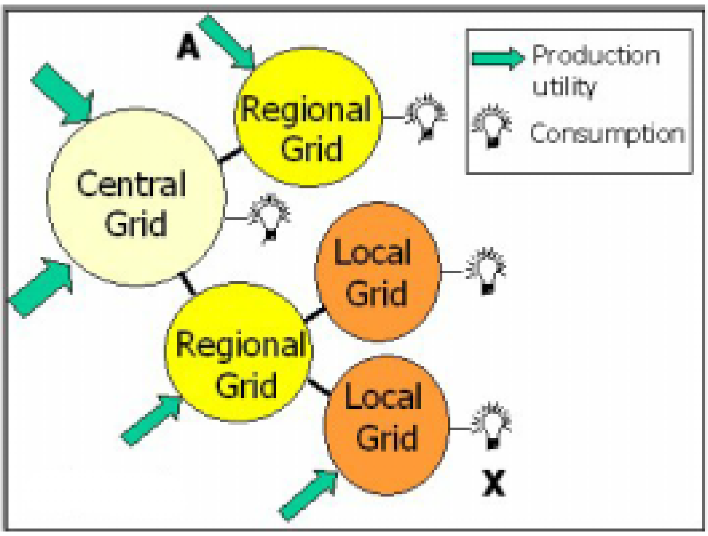

Figure 6: A schematic overview of the three levels of grid [35].

4. Conclusions

This paper provides a brief description of the structure, operational model and advantages of the computational power grid. A comparison between two different physical systems namely the electrical power grid and the computational power grid is also presented in the paper. It is observed that while the electrical power grid is one of the most advanced and evolved grids in existence, the computational grid can be considered to be a new and emerging field. Various analogous quantities have been identified and presented. Although there are still developments going on in the electrical power grid, this grid can be said to have reached a significant level of maturity. In comparison, it can be seen that the computational power grid is still in its infancy. A true computational Grid marketplace is yet to emerge. The use of computational Grids for solving real world problems is still limited to research labs and highly specialized scientific community funded by government agencies. Major advances in grid programming, application development tools, application and data level security, and grid economy are needed to push Grids into the mainstream computing. It is in a state in which the electrical power grid was almost a century ago. The paper has identified certain areas such as the need for an operational model (regulated system or otherwise), proper division of computational grid into regional pools, a coordinated system operation for the purpose of network stability, ease of use that needs to be addressed on priority.

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