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Power System Stability Enhancement through Smart Grid Technologies with DRS

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ABSTRACT

Smart grid is a new developing concept in power system. This technology observes the state of power system and intelligently take decisions to quickly clear faults, restores power and monitor demand to preserve the stability and performance of the electric power network formerly done by engineers. This paper discusses the technologies of smart grid and presents a developed model to illustrate the implementation of Demand Response System (DRS) in the distribution network of the smart grid. It also reviews the potential benefits as compared to the traditional power system grid. Finally, future challenges of the smart grid are highlighted.

Keywords: *Smart grid, Demand Response System (DRS), power system, potential benefits, future challenges*

1. INTRODUCTION

A smart grid which is also known as intelligent grid is the next generation grid in a form of electricity network utilizing digital technology. It delivers electricity from suppliers to consumers using robust two-way digital communications to control appliances at consumers' homes; this could save energy, increase reliability and reduce costs as well as transparency if the risks inherent in executing massive information technology projects are avoided. Smart grid is also the integration of communications networks with the power grid in order to create an electricity-communications super-highway capable of monitoring its own health at all times, alerting officials immediately when problems arise, and automatically taking corrective actions that enable the grid to fail gracefully and prevent a local failure from cascading out of control, as happened in August 14, 2003. Therefore, smart grid implies a fundamental re-engineering the electric services industry, but focuses on the technical infrastructure. Several contributions have also been made in regards what features the smart grid should possess [1], some features considered include load adjustment, greater resilience to loading, decentralization of power generation, price signalling to consumers and demand response support [2-5].Various designs has evolved in view of realizing this features by providing illustrations of what could be achieved in the smart grid system [6]. In this paper, we present a model to illustrate an implementation of Demand Response System (DRS) in the distribution network of the smart grid. The system utilizes the two-way communication between load and generators obtainable in the smart grid system. A typical example of smart grid with DRS is shown in figure 1.

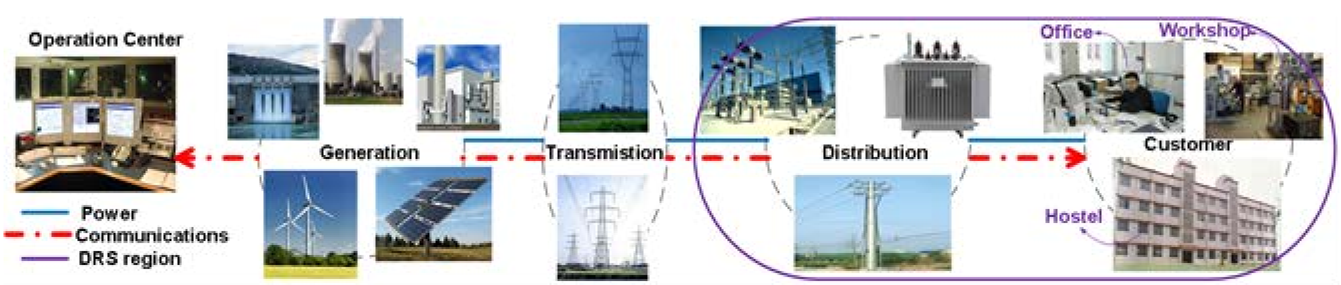

Figure 1: An example of a smart grid with DRS

The function of an Electrical grid is not a single entity but an aggregate of multiple networks and multiple power generation companies with multiple operators employing varying levels of communication and coordination, most of which is manually controlled. Smart grids increase the connectivity, automation and coordination between these suppliers, consumers and networks that perform either long distance transmission or local distribution tasks.

- Transmissions networks move electricity in bulk over medium to long distances, are actively managed, and generally operate from 345kV to 800kV over AC and DC lines.

- Local networks traditionally moved power in one direction, "distributing" the bulk power to consumers and businesses via lines operating at 132kV and lower.

This paradigm is changing as businesses and homes begin generating more wind and solar electricity, enabling them to sell surplus energy back to their utilities. Modernization is necessary for energy consumption efficiency, real time management of power flows and to provide the bi-directional metering needed to compensate local producers of power. Although transmission networks are already controlled in real time, many in the US and European countries are antiquated [7] by world standards, and unable to handle modern challenges such as those posed by the intermittent nature of alternative electricity generation, or continental scale bulk energy transmission.

2. TECHNOLOGIES OF SMART GRID

The existing or conventional electricity grid is unidirectional in nature. Figure 2 depicts fuel energy conversion of the existing electricity grid. It converts only about 33% of fuel energy into electricity, without recovering the waste heat which is about two-third of the fuel energy. Only about 20% of its generation capacity exists to meet peak demand while 8% of its output is lost along its transmission lines, this implies that the useful energy at this time is 5% [8-10]. Besides, the existing electricity grid suffers from domino-effect failures as a result of its assets hierarchical topology.

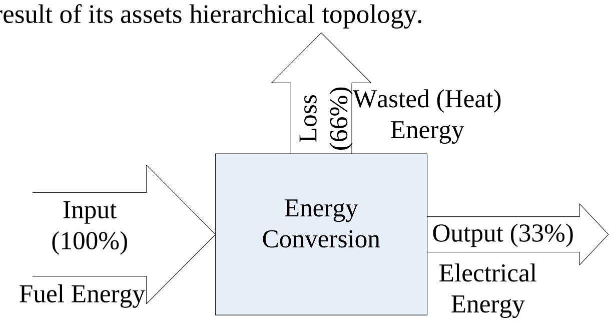

Figure 2: Fuel energy conversion of the conventional electricity grid

The major limitations of the existing or conventional grid are expected to be addressed by smart grid [11-12]. Table 1 shows very good comparison of the conventional (existing) grid with the smart (new generation) grid. Smart grid combines communication technology and information technology with power systems engineering to allow pervasive control and monitoring. These two basic ingredients (information and communication) management play a vital role by allowing the introduction of new applications.

Table 1: The Comparison between the Conventional Grid and the Smart Grid

Smart Grid	Conventional Grid
Self-Healing	Manual Restoration
Digital	Electromechanical
Pervasive Control	Limited Control
Two-Way Communication	One-Way Communication
Distributed Generation	Centralized Generation
Network	Hierarchical
Adaptive and Islanding	Failures and Blackouts
Sensors Throughout	Few Sensors
Remote Check/Test	Manual Check/Test
Self-Monitoring	Blind
Many Customer Choices	Few Customer Choices

Everybody talks about vision 2020; this vision might be a mirage if smart grid is not allowed to take over the conventional grid gradually. The United State President Barack Obama once said that “We will fund a better, smarter electricity grid and train workers to build it – a grid that will help us ship wind and solar power from one end of this country to another” [13]. He talked about smart grid and how it will gradually take over the exiting grid as the technologies advances. Therefore, as there is advancement in technologies, there is need for an energy management system.

There are different features of smart grids as shown in figure 3. This comprises the new solution of active resources like loads, distribution generations, electricity vehicles, customer e.t.c and future infrastructure of power distribution such as cabling in large scale. The active resources really transformation the existing passive distribution network to be an active one. It also includes new networks solutions for asset management providing intelligence to active networks and also new software tools. Smart grids also permit active market participations, energy management and have strong control on change in

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business environment (i.e regulation, deregulation and service purchasing)

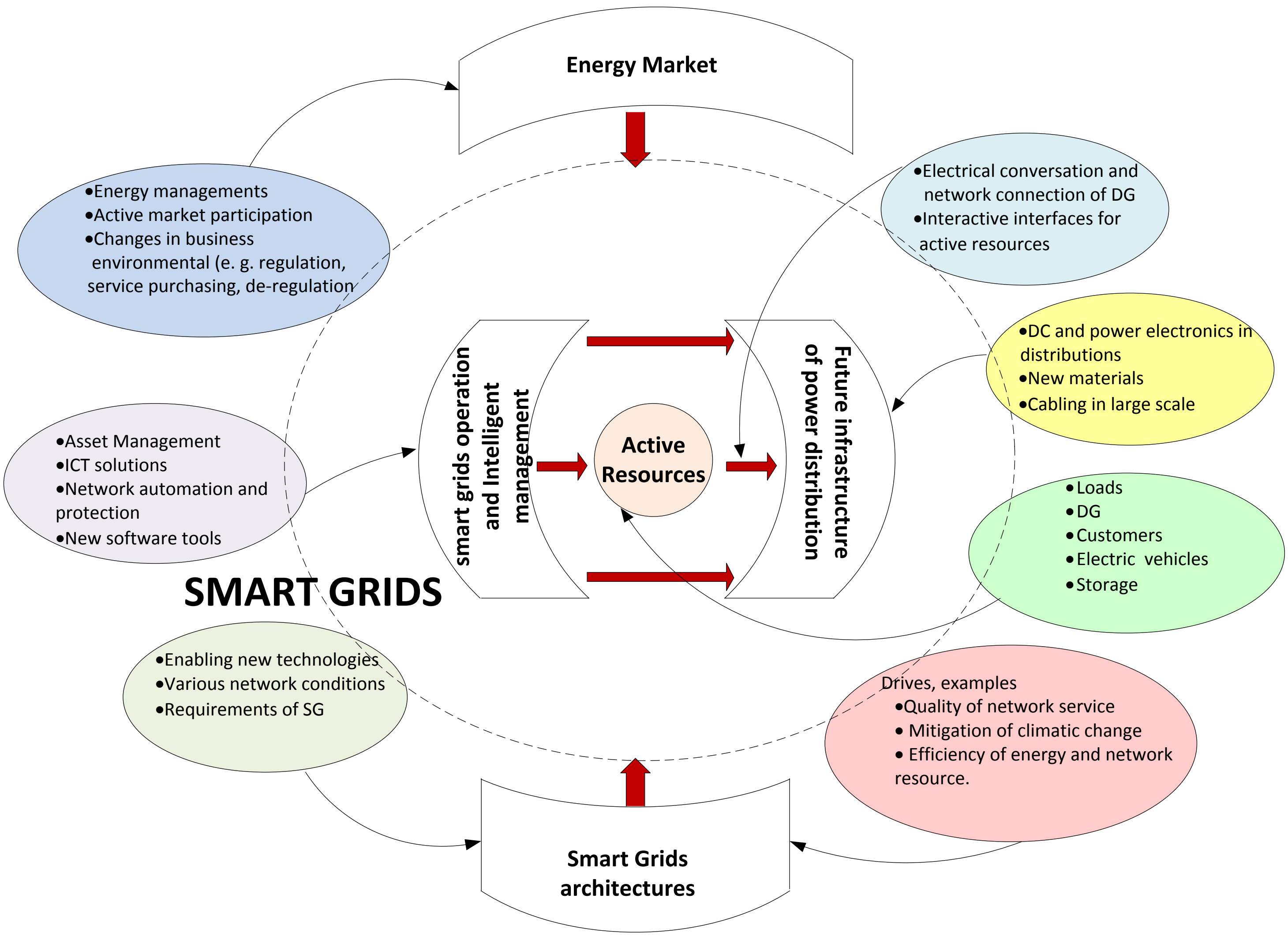

Figure 3: Technologies of smart grids

In a nutshell, smart grid technologies may be characterised by the following three words; intelligence, Integration and flexibility. Intelligence has been defined in different ways, including the abilities for abstract thought, understanding, communication, reasoning, learning, planning, emotional intelligence and problem solving. This technology involving the intelligence of smart grids is investments on power system protection, ability to control telecommunication and information technologies as an alternative to pure passive cables, lines, switchgears transformers. The flexibility aspect is to make the network itself to handle all likely loading conditions i.e. smart grids utilize controllable resources throughout the network. One of the benefits of properly managed network in distribution network of smart grids is the integration of flexible loads and the distributed generation (DG) and this will tremendously improve the overall system performance. Other benefits are discussed in section 3.

3. DEMAND RESPONSE SYSTEM (DRS) IN THE DISTRIBUTION NETWORK

Demand Response System (DRS) is the ability of the smart grid to respond to consumers varying demand in an automated real time fashion. This enables the system to vary supply to consumers in an attempt to meet their instantaneous demand. This system which is part of figure 1 employs load-forecasting techniques to predict when peak load will occur and optimize algorithm that can then be applied to flatten or reduce the peak load. The system consists of two distinct parts: the distribution software and the hardware module.

a. Distribution software

The distribution software program was written in java language which was designed using the Netbeans IDE 6.8. Figure 4 shows the Netbeans window.

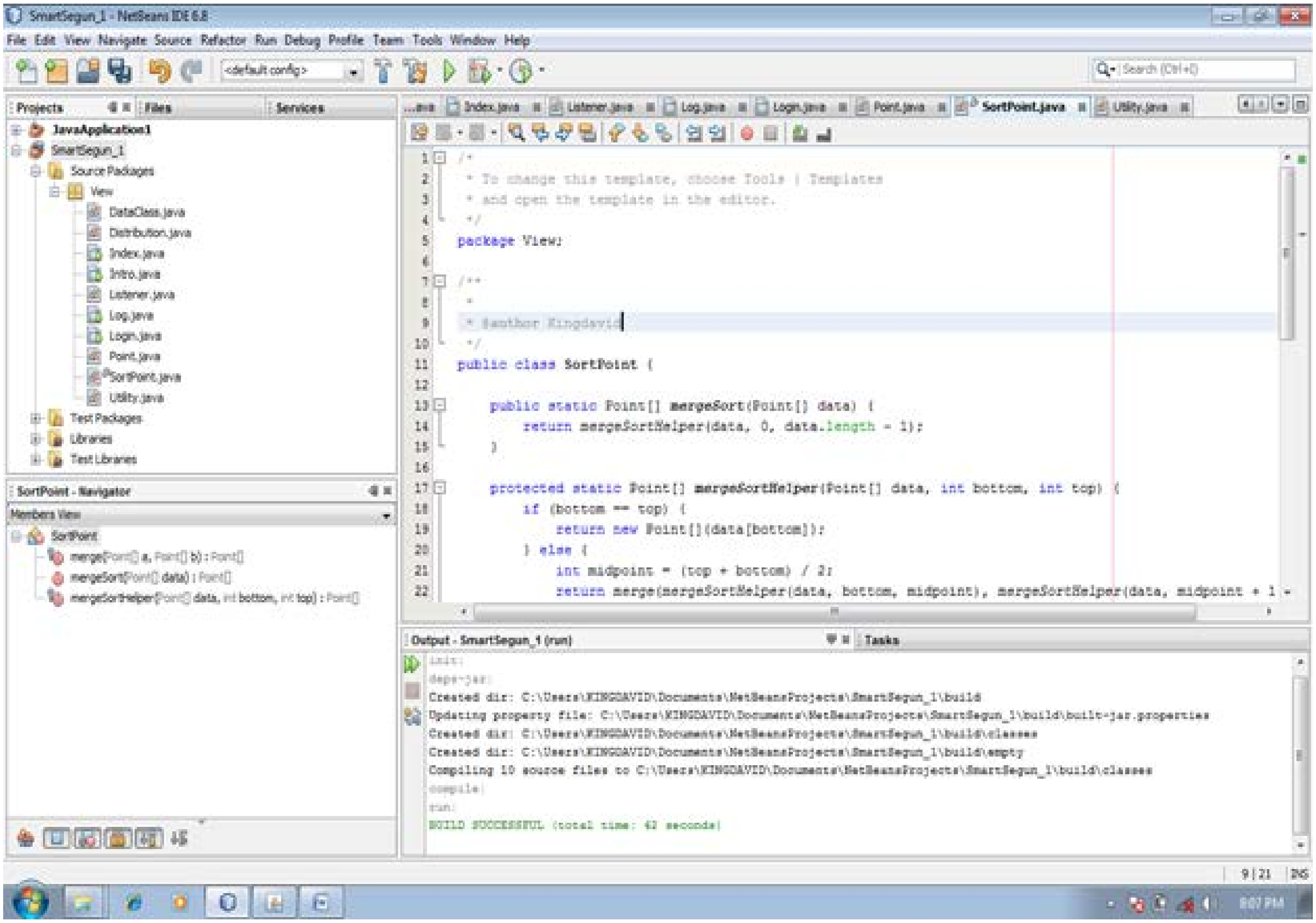

Figure 4: Netbeans IDE 6.8 window

The software performs the following functions:

1. Receives input from the hardware module and attends to this data in real time.
2. Displays the total available power and its allocation to each load unit, current value of power not used (if any), preset base power that can be allocated to each load unit and priority of supply to these load units.
3. Shows changes in total power available for supply when there is change in supply input to the system.
4. Update load distribution database with changes in power demand and corresponding supply to various units against the time of change.

The flow chart diagram and graphic user interface of the software is shown in the figures 5 and 6 respectively

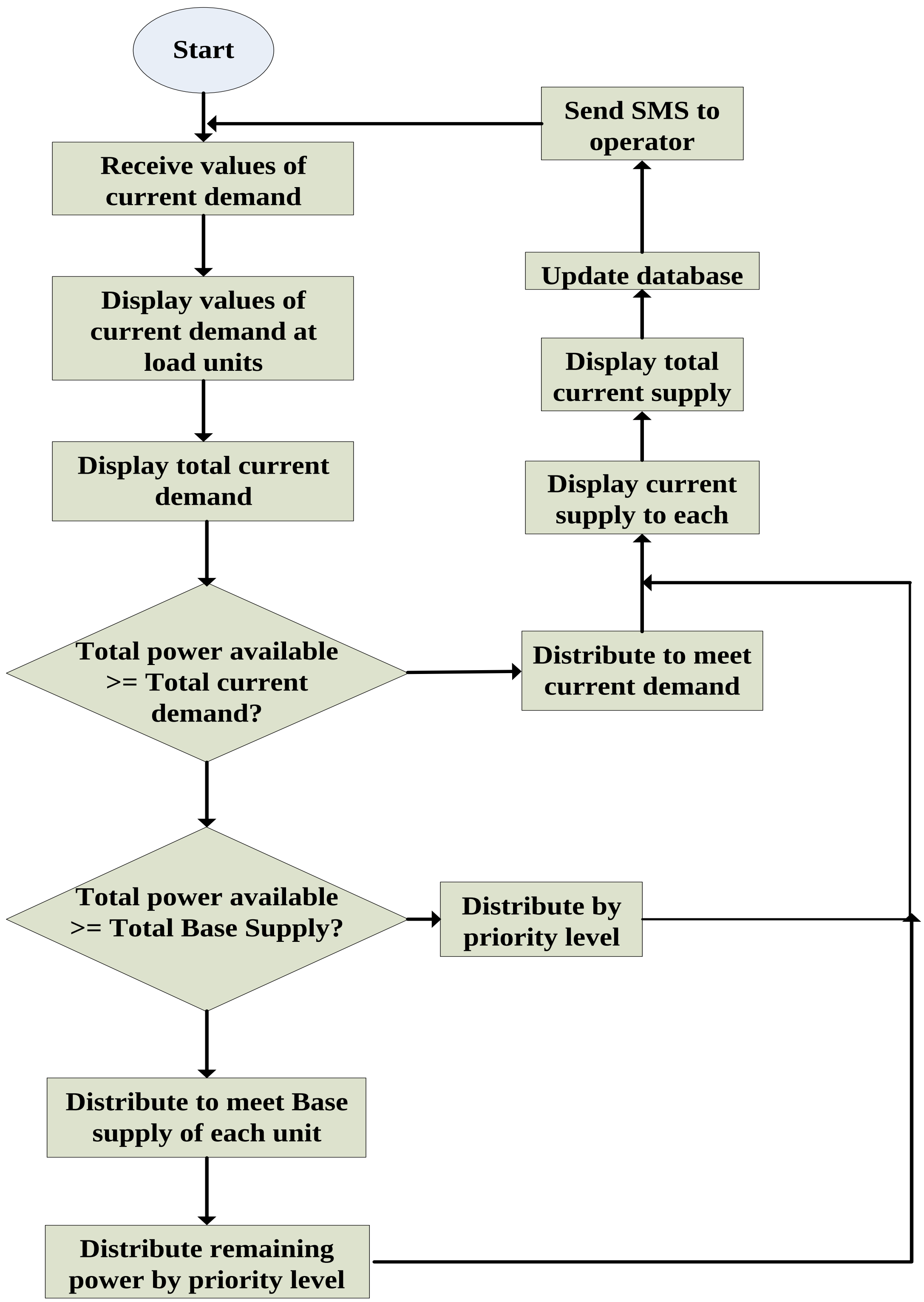

Figure 5: Software Flow Chart Diagram

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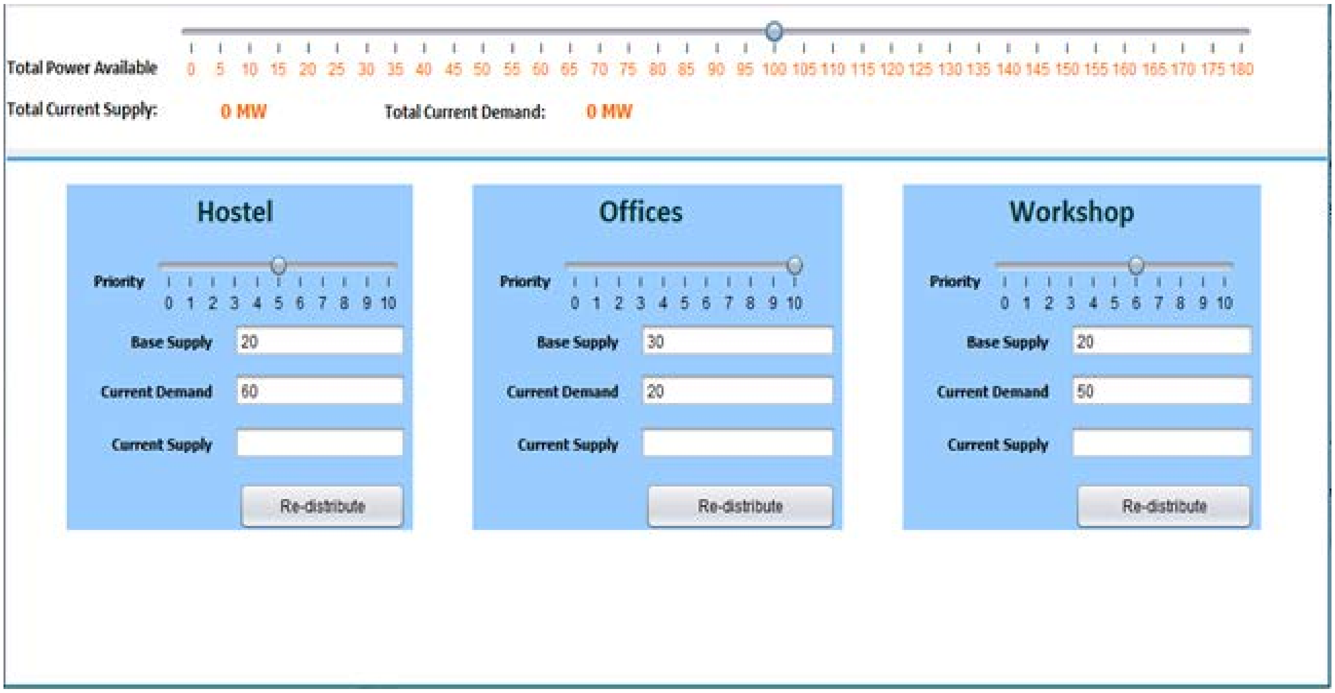

Figure 6: Distribution Software Graphic User Interface

a. Distribution Hardware Module (Load Units)

The hardware module comprises of load units which are interfaced to the computer through the communication ports of the microcontroller. It performs the following functions:

1. Displays the load values for each unit via a connected Light Emitting Diode (LED)
2. Varies the load value with time so as to create a continuous simulation of the load consumption at each load units.
3. Sends these load values (in 2 above) to the serial port of the general purpose computer system.

To illustrate the performance of this system, power distribution between three campus buildings (HOSTEL, OFFICE and WORKSHOP) were considered. Each unit can have one of the four load values (20, 40, 60 and 80) in megawatt (MW). These values are represented by Light Emitting Diodes (LED) connected to a microcontroller. At every time the microcontroller turns on a LED to indicate the load at the time show the time via a seven segment display and send the corresponding load value to the distribution software. When the system software initialized and the hardware counterpart activated, the power distribution obtained for different load values at the load units at different times are displayed as shown in figure 6. Table 2 power distribution (Load) between three campus buildings (HOSTEL, OFFICE and WORKSHOP) in response to their varying demand and an update is also performed on the database as shown in figure 7. Thus, Demand Response System (DRS) provides an efficient power distribution in a smart grid.

Table 2: Power Distribution (Load) between three Campus Buildings in Response to their Varying Demand

Time (24hrs)	Hostel Loads (MW)	Office Loads (MW)	Workshop Loads (MW)
00	40	20	20
02	20	20	20
04	20	20	20
06	40	20	20
08	60	40	40
10	40	60	60
12	20	60	80
14	20	60	40
16	60	40	40
18	80	20	20
20	80	20	20
22	60	20	20

4. BENEFITS OF SMART GRID

The electric power system is on the verge of significant transformation. The electric energy in world demand is expected to rise 82 per cent by 2030 [14]. Except revolutionary new fuels are developed, this demand will be met primarily by building new coal, nuclear, and natural gas electricity generation plants. Not surprisingly, world CO_2 emissions are estimated to rise by 59 per cent by 2030 as a result. The Smart Grid can help offset the increase in CO_2 emissions by slowing the growth in demand for electricity; this implies that vital per cent of global greenhouse gas would be removed.

A Smart Grid that incorporates demand management, distributed electricity generation, and grid management allows for a wide array of more efficient, "greener" systems to generate and consume electricity [15]. In fact, the potential environmental and economic benefits of a Smart Grid are significant. A recent study, providing homeowners with advanced technologies for accessing the power grid to monitor and adjust energy consumption in their homes. The average household reduced its annual electric bill by 10 per cent [16]. For the about six years, work has been under way to conceptualize the shape of a 21st-century grid that exploits the huge progress that has been made in digital technology and advanced materials. The benefits of smart grid cannot be fully discussed or explored in this paper, but other few benefits are discussed below.

A Smart Grid will:

a. **Be able to heal itself**-Smart grid expects and instantly responds to system problems in order to mitigate or avoid power outages and power quality.

b. **Motivate consumers to actively participate in operations of the grid**-Improved system reliability will create benefits for consumers. However, perhaps the most significant benefits arise from more empowerment and individual control over energy use and monthly bills. Smart grid can provide a new set of tools for consumers to manage their usage and total energy bills. Smart grid technology makes it easier and cheaper for consumers to see their electricity use and to have access to value-enhancing dynamic pricing, if they desire it. Finally, by connecting prices and quantity of usage, customers will be transformed from passive "ratepayers" to active, engaged participants in electricity markets.

c. **Enable electricity markets to flourish**- Significant increases in bulk transmission capacity will require construction of new transmission lines before improvements in transmission grid management proposed by smart grids can make a difference. Such improvements are aimed at creating an open marketplace where alternative energy sources from geographically distant locations can easily be sold to customers wherever they are located. Intelligence in distribution grids are not required to enable small producers to generate and sell electricity at the local level using alternative sources such as rooftop-mounted photo voltaic panels, small-scale wind turbines, and micro hydro generators. For example Chelan PUD's SNAP program promotes distributed, consumer owned small scale generation. Only after very high penetration of these types of resources is additional intelligence provided by sensors and software designed to react instantaneously to imbalances caused by intermittent sources, such as distributed generation, necessary

d. **Accommodate all generation and storage options**- It accommodates a wide variety of generation options (i.e intermittent and dispatchable, central and distributed)

e. **Run more efficiently**- Increased asset utilization made possible by smarter energy management means more efficient power plant operation and fewer peaking units. Utilities stand to benefit from a higher rate of return on capital investment and lower costs.

f. **Resist attack**- Smart grid technologies better identify and respond to natural or man-made disruptions. One of the most important issues of resist attack is the smart monitoring of power grids, which is the basis of control and management of smart grids to avoid or mitigate the system-wide disruptions like blackouts. Real-time information enables grid operators to isolate affected areas and redirect power flows around damaged facilities. The traditional monitoring is based on weighted least square (WLS) which is very weak and prone to fail when gross errors (including topology errors, measurement errors or parameter errors) are present. New technology of state monitor is needed to achieve the goals of the smart grids.

Enable higher penetration of intermittent power generation sources- There will be increase in the amount of renewable energy resources as climate changes and environmental concern. These are for the most part intermittent in nature. Smart Grid technologies will enable power systems to operate with larger amounts of such energy resources since they enable both the consumers and suppliers to compensate for such intermittency.

5. FUTURE CHALLENGES OF SMART GRID

As stated in section 3, electricity's share of total energy is expected to continue growing in the coming decades [11], and more intelligent processes will be introduced into this network. For example, controllers based on power electronics combined with wide-area sensing and management systems have the potential to improve the situational awareness, precision, reliability, and robustness of power systems. It is anticipated that the electric power grid will move to an electronically controlled network from an electromechanically controlled system in the next two decades. However, the electric power infrastructure, faced with deregulation (and interdependencies with other critical infrastructures) and an increased demand for high-quality and reliable electricity, is becoming more and more stressed.

The "key challenges" to the future development of smart grid include:

- Strengthening the grid – ensuring that there is sufficient transmission
- Capacity to interconnect energy resources, specially renewable resources, across Europe
- Developing decentralised architectures – enabling smaller scale electricity supply systems to operate harmoniously with the total system
- Active demand side – enabling all consumers, with or without their own generation, to play an active role in the operation of the system
- Communications – delivering the communications infrastructure to allow potentially millions of parties to operate and trade in the single market
- Enhanced intelligence of generation, demand and most notably in the grid
- Capturing the benefits of distributed generation and storage
- Integrating intermittent generation – finding the best ways of integrating intermittent generation including residential micro generation
- Preparing for electric vehicles – whereas smart grids must accommodate the needs of all consumers, electric vehicles are particularly emphasised due to their mobile and highly dispersed character and possible massive deployment in the next years, which would yield a major challenge.
- Moving offshore – developing the most efficient connections for offshore wind farms and for other marine technologies

6. CONCLUSIONS

This paper showed brief overview of Smart Grid Technologies and how DRS can enhance power system stabilities in the distribution network. The DRS illustrated by three load units with varying demand and the output display shows that power is distributed to consumers in response to their varying demand. Most electrical power industries are experiencing rapid transformation. The technology is exhilarating, but the challenging times lie ahead. The rising cost of energy, climate change, and the mass electrification of everyday life are the key drivers that will determine the speed at which such transformations will occur. Irrespective of how quickly various utilities embrace smart grid concepts, technologies, and systems, they all agree on the unavoidability of this massive transformation. It is a move that will not only affect their organization and technologies but also their business processes. Simultaneously, many research centres across the globe are working to ease this transition by developing the next generation technologies required to realize the smart grid.

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