Final Assignment

Submitted by: Arbab Muhammad Adnan

Submitted to: Dr. Sohail Imran Saeed

Question 1

The grid that is initially designed for one-way power flow is now experiencing two-way flow of power. As the grid is transforming to micro grid and smart grid it gives rise to new debate for the power system intellectualist whether to invest in conventional grid model (generation + transmission + distribution) or to invest in storage model (distributed generation + distribution + storage).

Discuss in detail the major factors/ issues preventing Pakistan to shift to smart grids. Also give a detailed overview of how Pakistan can take benefit of smart grid in her quest for power sufficiency?

Answer:

Smart Grid:

Worldwide electrical energy consumption was at 17313 tera watt hour (TWh) in 2009 but this was not evenly distributed. It was estimated that about 260 million households did not had access to the power grid for various reasons including technological and economic barrier, natural obstacles, communities which are located in islands, environmental constraints, and high distance. A system is known as a smart grid which implements communication and information technology in electrical grid. It develops communication based monitoring and controlling for the load utilization improvement of the consumer by collecting information about the ongoing activities of electrical energy suppliers and consumers. Smart grid system consists of advanced sensing technology, control algorithm communication infrastructures and actuators for rapid diagnosis and power outrages prevention Smart grid technology is becoming an important area of modern research that takes into account the evaluation of design and operations, integration of distributed resources, and power stability improvements in grid.

Existing technology has changed our life style, but our current electric grid system which we trust for to keep supplying power to domestic users which includes our houses, places of work, health care has not been updated to meet required demand therefore exponential growth in the demand of electricity has also brought forth the need to efficiently use electricity by optimizing the production, minimizing the losses and efficiently managing the loads. The concept of "Smart grids" has emerged due to the fact that efficient management of loads can provide a potentially strong solution to optimize the energy consumption in an intelligently controlled smart environment. This new technology requires an advanced control system that can use the potential of bidirectional communication. In a smart grid environment there is continuous and effective communication between the consumer based and grid based smart controllers which also used for load optimization. A simple architecture of smart grid is shown Figure 1 in which power generation will be provided via nuclear power plant, thermal power plant and renewable section.

A smart grid will act as smart distribution unit. Factories, Homes and offices are connected as a load. Vehicle will be driven via battery banks.

Benefits of Smart Grids:

1) Smart Grid Overhauls Aging Tools.

The traditional grid system is old and it depends upon that equipment's which are near to end of its usable life. Smart grids help to update this old infrastructure and ensure the reliability values continue to be met, Power is delivered constantly to the consumer and overall system would be manage efficiently.

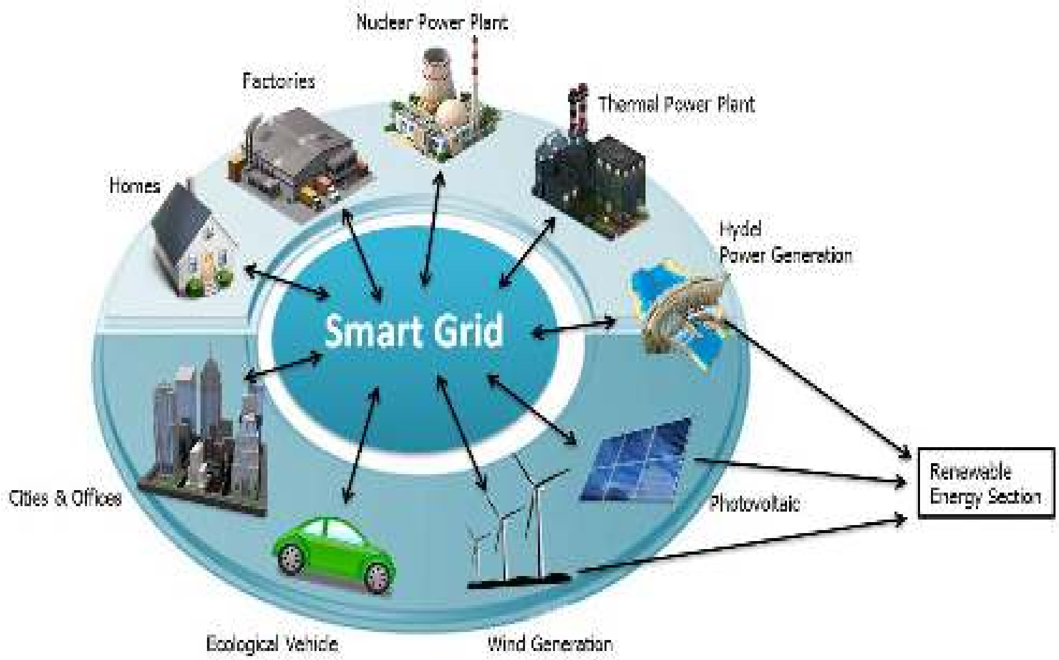

Figure 1: A simple Architecture of Smart Grid

2) Smart Grid Help Main Utility Grid to Meet Rising Demand.

As everyone today use electrical energy and electronic devices than ever, therefore the demand for power increasing continuously. Smart grids improve the old system which is strained to near capacity.

3) Smart Grid Decreases Brownouts, Blackouts, and Surges.

Smart grid is the only solution for the smooth power flow and in such systems if fault occur they can recover and manage system easily as compare to the traditional grid system.

4) Smart Grid Provides a Complete Control to Consumer.

A smart grid technology will monitor and manage your energy through home management system and will also use energy wisely through smart meters. A consumer can schedule and control his energy task. In this system consumer can monitor his/her load efficiently. Only this system allows the end user to communicate in both ways in order to reduce energy consumption during peak time, maximize the use of renewable as well as minimize the usage of main utility grid. For example, the load shifting technique at consumer side is applied in a case study of 1000 households for experimental basis. Without smart grid technology, traditional grid was unable to meet demand at peak hours whereas with the help of smart grid technology peak load had been reduced 8% at consumer side via load shifting technique.

A comparison of traditional power systems with smart grid is shown in Table 1

Traditional Power Systems	**Smart Grid Power System**
Electromechanical	Digital
No communication or one sided communication	Communication from both sided
Centralized power generation	De-Centralized power generation from renewable
Hierarchical configuration	Network configuration
Sensors and fundamentals have limited capacity	Broad measurement of sensors and fundamentals
A network of no feedback	The intrinsic and real-time control
Manual recovery	Automatic recovery
Large disturbance at time of power outage	Fault filtering island disconnection
Manually assessment and estimation network	Remote assessment and estimation network
Restrictive control	Wide-ranging control
Restricted facility to consumer and subscriptions	A variety of facility to consumer and subscriptions

Table 1: Traditional Grid Vs Smart Grid

Pakistan, a developing country, full of natural resources and manpower with population exceeding 176.74 million has a lot of potential in fulfilling its energy requirements. However, the country is facing severe shortage of electricity due to overloading, mismanagement, transmission line losses, electricity theft issues, aged equipment, poor maintenance and questionable monitoring and control. These issues have really put the power sector to a downfall. In Pakistan, transmission line losses are very high as compared to other countries. Each year these losses are increasing which is becoming a challenge for the country. Existing aged Transmission Grids (TGs) are very poorly managed, rendering them unreliable, insufficient, and unaffordable. Intelligent energy management using advanced digital technology combined with power electronics and sensors can greatly improve transmission lines efficiency.

With the advancement in technologies, the power requirement around the globe is tremendously increasing, putting extra loads on grids. The existing grids cannot bear that load and also do not provide the interface with Distributed Renewable Energy Sources (DRES). Building new lines and substations alone do not serve the purpose of overcoming energy shortfall. Thus a major transformation in electricity infrastructure is need of the hour to meet the ever growing demands of electricity. Converting current power management system to a smart autonomic system is pertinent to achieve an increasing amount of renewable energy generation. Renewable energy has potential to eliminate the current electricity crisis in Pakistan's energy sector. The solar, wind, hydro and biogas/biomass are the alternative energy resources found abundantly in the country, which have tremendous potential to offer environment-friendly energy solutions. This in-depth study reveals that a lot of opportunities and potential of smart grid technology exist in developing countries like Pakistan that need to be exploited so as to cope with energy crisis.

For the growth of an economy, the satisfactory and steady availability of energy supplies is necessary. A developing country (like Pakistan) encounters perpetual issues of power losses.

The present electric power system structure has lasted for decades; it is still partially proprietary, energy-inefficient, physically and virtually (or cyber) insecure, as well as prone to power transmission congestion and consequent failures. Recent efforts in building a smart grid system have focused on addressing the problems of global warming effects, rising energy-hungry demands, and risks of peak loads. One of the major goals of the new system is to effectively regulate energy usage by utilizing the backbone of the prospectively deployed Automatic Meter Reading (AMR), Advanced Meter Infrastructure (AMI), and Demand Response (DR) programs via the advanced distribution automation and dynamic pricing models. The function of the power grid is no longer a system that only supplies energy to end users, but also allows consumers to contribute their clean energy back to the grid in the future. In the meantime, communications networks in the electric power infrastructure enact critical roles. Intelligent automation proposed in smart grid projects include the Supervisory Control and Data Acquisition/Energy Management Systems (SCADA/EMS) and Phasor Management Units (PMU) in transmission networks, as well as the AMR/AMI associated with field/neighborhood area networks (FAN/NAN) and home area networks (HAN) at the distribution and end-use levels.

Pakistan is under energy crisis for past few decades. NEPRA (National Electric Power Regulatory Authority) state of industry report 2011 shows per capita electricity consumption in Pakistan is 465kWh/annum which is still amongst one of the least consumers list. Total number of consumers of electricity in Pakistan is 22.42 million with installed capacity of 23412MW. Power sector is facing huge problems in terms of load shedding, blackout, theft issues, meter malfunction and tempering, high T&D (transmission and distribution) losses etc. Total peak demand has crossed22,765 MW. Pakistan is experiencing a severe energy crisis that has devastated its economy. In Pakistan T&D losses have increased beyond 19.5% and these line losses result in loss in material strength and insulation weakening, as well as due to the technical and non-technical reasons that should be addressed properly to cope with this problem. Pakistan power sector is under control of WAPDA (Water and Power Development Authority) and KESC (Karachi Electric Supply Company). All power is being supplied to Nation by WAPDA except Karachi city which is handled by KESC. Both these entities are connected by double circuit transmission line of 220 kV. Lack of technical expertise and mismanagement along with aged equipment and existing transmission system infrastructure has caused a monotonic increase in T&D losses.

TABLE I
POWER TRANSMISSION LINES LENGTH IN PAKISTAN

No.	Voltage	Length
1	500kV	5023 cct-kms
2	220kV	8103 cct-kms
3	132kV	Over 20000 cct-kms

SOURCE: NEPRA STATE OF INDUSTRY REPORT

TABLE II
POWER TRANSMISSION SYSTEM IN PAKISTAN

No.	Grid Station	Numbers	Transformation capacity
1	500kV	12	15990 MVA
2	220kV	37	18800 MVA
3	132kV	Over 650	

SOURCE: NEPRA STATE OF INDUSTRY REPORT

Table I and Table II are giving information about the transmission line length and total number of transmission girds in operation. Due to insufficient inter-regional transmission networks, lack of proper utilization of existing transmission girds and theft issues etc., there is a need to upgrade the aged TGs to STGs using emerging technologies. But this will take some time for the country like Pakistan which is facing many technical (internal to the system) and non-technical (external to the system) challenges for decades. Technical challenges are faced in the form of Technical

Losses (TLs). These TLs are internal to the system which occurs during the transmission of electric power. They mainly consist of power dissipation in transmission lines, power transformers, electronic monitoring, measuring and controlling devices etc. To compute and control TLs, power system under investigation should have all information related to the known quantities of load being driven. Some important technical challenges being faced by Pakistan are as follow:

A. Ecological Confrontation

Electricity produced for the domestic, industrial and commercial use has an obvious effect on greenhouse gas (CO2) emission which is mainly the result of fossil fuels combustion. It is reported by international resources group (IRG) that major sources of CO2 emission in Pakistan are power plants and industrial sector.

B. Emerging Technologies

To rejuvenate old transmission system, new state-of-the-art technologies should be used like, IoT (Internet of Things) for enhancing online security, protection and disaster prevention of power lines. As fault points of power transmission lines are scattered, haphazard and difficult to detect and maintain but in Pakistan such faults are fixed using old techniques that waste time and money and cause significant loss to economy. Similarly, using advanced materials, sensors, controlling, computing resource, fuzzy logic reasoning, knowledge discovery, self-learning etc., would lead to Smart Grid, Future Grid, Intelli Grid etc. To incite power sector inclination for emerging technologies is a huge challenge to step forward to STGs.

C. Consumer Support

Lack of Customer interaction with TG and poor price and quality of consumed electricity would lead to consumer dissatisfaction. Proper transparency in policies implementation and adoption of new technologies for resolving customer issues in reasonable power transmission will be extremely helpful. Similarly, absence of consumer privacy, security and educating them to adopt smart appliances is needed to meet smart transmission vision in Pakistan.

D. Automatic Monitoring and Control

For reliable and high quality power transmission to the end users, automatic power transmission system is needed using all smart technologies for efficient monitoring and control. This can be fulfilled by using either state estimator technique that collects data from RTUs (Remote Terminal Units) or SCADA (Supervisory Control and Data Acquisition) system or by PMUs (Phasor Measurement Units) that gives state variables (voltage and current angles) from synchronized phasor signals giving better reliability and efficiency. But unfortunately such monitoring and control of transmission system requires a lot of investment and stable economic conditions for a country like Pakistan, whose economy is constantly in decline state, so it will take time to overcome this challenge.

E. Existing Transmission Grid

All TGs in operation today, are being handled or monitored by conventional techniques. Lack of technical expertise and trainings for staff professional development as well as aged equipment and instruments installed, T&D losses have increased their limit. In such situation to equip existing TG to STG is required to minimize all such losses.

F. Data Transmission and Processing

To manage and share all data required from sensors and instruments installed on transmission line network, a strong database management system is required, for data acquisition, processing and transmission to the control centers, so that if any fault is detected, can be removed within minimum time ensuring continuous power transmission to the users. Although basic infrastructure and architecture has not been changed over decades of transmission system but for data collection and monitoring microprocessor based equipment is desired. Moreover, high accuracy of time stamped signal can be achieved by GPS. Enormous data intrusion can be checked with the help of fault recorders using intelligent devices. Data available from RTUs (Remote Terminal Units), can be sent to central database that is difficult to handle for this we prefer distributed database e.g. SCADA system with the help of some middleware to increase system reliability and efficiency. To achieve this goal proper designing and planning is required in Pakistan.

G. Power Quality, Sustainability and Reliability (PQSR)

Lower economic growth of a country reduces both the energy consumption and the investment required to meet the demand hence disturbing the PQSR concept. Pakistan is facing huge power outage in rural and urban areas due to many factors like purchasing fuel cost to run power plants, poor maintenance and repairing of equipment, low speed fault locators, unable to reconfigure existing TGs.

H. Advance Power Electronics, Intelligent Technologies

TGs in Pakistan are unaware from advanced technologies of power electronics, advanced Flexible AC Transmission Systems (FACTS), High-Voltage Direct Current (HVDC) devices, smart sensors, instrumentations and measurements; rather they are following the obsolete methods of grid handling, due to unavailability of the skilled staff, limited resources and investment. Use of advance power electronics for efficient transmission and IEDs (Intelligent Electronic Devices) to improve fault location precision in transmission is the requirement for STG.

I. Communication Technologies

For reliable and continuous power transmission in STG realization, there is need for smart and intelligent communications networks like IEEE 802.11 based wireless LAN, DASH 7, IEEE 802.15 based ZigBee, IEEE 802.16 based WiMAX, Power Line Communication (PLC), 3G/4GGSM. But data collection, storing, speed, architecture designing, cyber security and access control are issues that should be addressed strictly and resources limitation is a big problem in the development of STGs. Huge investment along with planning is required to build such communication network.

J. Transmission Line and Tower Protection

Multifunctional protection schemes for transmission lines are one of the important concepts in STG. Hence primary and backup protection can be provided by using IEDs Similarly any damage to transmission tower can be fully monitored and controlled based on IoT (Internet of Things) through sensing networks of wireless sensors. Protection from lightening can be provided using different methods including lightning arresters, air terminal, pipe-pipe gap, underground cables and grounding systems.

IV. NON-TECHNICAL CHALLENGES

Challenges that have been faced for many years in power sector of Pakistan are losses due to non-technicalities. These challenges owe Non-Technical Losses (NTLs), they can be due to human manipulation or malfeasances and therefore external to the power systems. Non-technical losses are very difficult to measure. NTLs are not only being faced in developing countries but also an issue for developed countries. NTLs are impossible to remove completely however with strategies and proper planning these losses can be reduced to cope with this challenge. Pakistan's Minister for Water and Power reported a loss of Rs.90 billion during last five years (2007-2012) in line losses and electricity theft. NTLs are frequently observed on medium and low voltage T&D lines. Some of the main causes of NTLs are discussed as follow:

A. Manual Inspection

Such inspection of meters to take false readings has been in practice for decades in Pakistan which means lower staff with mutual interest and understandings of meter owners gets involved and take bribery. Temptations offered by meter owners are big challenges to eradicate this problem which is one of the major reasons of NTLs in my developing countries.

B. Electricity Theft

Reducing amount of money by a person that one owes the utility for electric energy is the form of theft. It may be either an illegal connection or self-line constructions. Central Power Purchasing Agency Pakistan reported 10 billion units of electricity were lost during 2010 due to leakages and theft. This huge ill legal activity can't be done without the involvement of staff. Similarly, Development of Demand Side Management (DMS) software that include management of energy efficiency incentive programs, load management, dynamic pricing, and billing, load control and smart metering can help minimizing this issue well.

C. Meter Tempering, Malfunction

Meter related issues are big challenge to minimize the NTLs. Although, smart meters are being used in some domestic and commercial areas but not widely used all over the country. This makes meter tempering, by passing or incorrect reading by old meters. Investment is needed to resolve this issue by replacing old meters with smart meters to control theft issues in Pakistan.

D. Non Bill Payments

Non-payments by customers or error and delays may cause this loss to be accounted as NTLs. This problem may arise due to ignoring unpaid bills. These losses are itself a challenge to compute easily. For this proper planning and management system is required to get back such non bill payments by the users.

E. Equipment Deterioration, Miscalculations

Poor maintenance of equipment's leads them to show false reading and miscalculations. Such problems occur frequently in power transmission side as well on distribution side. Old monitoring and controlling instruments need to be checked on regular basis otherwise such issues arise and increase NTLs.

F. Espionage and Insurgency Hazards

Pakistan has been in the state of war for many years, terrorism and bomb blasts have devastated its economy badly. Such image repelled companies to come and invest here. This problem has raised the unemployment, instability and has forced the professionals, engineers and skilled workers to move to the other countries for their livelihood.

G. Political Illegitimacy

Political interference has a big part in current situation of the Pakistan power sector today. Power generated by IPPs and rental power plants has high tariffs and not affordable but due to corruption and high commissions involved; it is difficult to get rid from such political interference. Investment is not being made in renewable energy resources to find out other means of cheap electricity to overcome this energy shortage.

NEED FOR Smart Transmission Grid (STG) IN PAKISTAN AND ITS ADVANTAGES

Identifying all of the factors given in previous section individually and taking measures to control is very costly and inefficient for a bigger country like Pakistan. Detection of losses by conventional methods in a big country is also in appropriate. By the usage of smart grids, the expenditure involved in domain of revenue protection can come down considerably.

To cope with all these Technical and non-technical challenges explained in the above sections, we can deploy STG in Pakistan to boost up the countries power sector, that will eventually grow its economy. Advantages that can be gained from STG implementation are as follows:

A. Self-Healing and Diagnosis

A smart grid is capable to diagnose and respond to faults and quickly recovers if they occur, minimizing downtime and financial loss to the system. Similarly using technologies of sensing, data transmission, processing and telecommunication to check and monitor online operating conditions of power lines, transformers, relays, circuit breakers etc. Smart transmission facilitates prompt diagnosis using smart sensor technologies i.e. online monitoring and control based on synchronized measurements and assets condition monitoring for stable operation.

B. Online Monitoring and Control (OMC)

A shift of control centers, based on state estimators to phase measurement units (PMUs) are being planned to be used in the future as it is more robust and efficient. GIS will take part in visual display of control centre preventing maloperation. To detect fault location, frequency wave technology can be used to make monitoring more accurate. Similarly, Priority based alarming system can help operator to provide vivid monitoring.

C. Advanced Metering Infrastructure (AMI)

In Integrated SG applications, AMI facilitates utilities to use automatic controls to limit electric energy usage at peak times, reduce consumer’s bills, save energy and hence giving financial benefits for power sector. This process is environment friendly, efficient, and lessens the need to build new facilities. Interoperable STG restores the demand and supply balance while creating efficient energy markets. When it comes to improving resource management, revenue opportunities, and customer service through the use of SG strategies, it introduces interoperable infrastructure that delivers the functions and benefits of the STG by overcoming technological challenges.

D. Advanced Data Transmission and Management Facility

Issues frequently faced in transmission lines protection and repair e.g. tower leaning, conductor galloping, wind deviation, icing, vibration, conductor temperate and humidity, sensors which are monitoring should have common communication protocol to support self-healing communication network for data transmission, for this a standard protocol i.e. IEC 61850 open to all heterogeneous devices that increases the interoperability significantly. STG gives the concept of strong database management system, coming from different devices, sharing this date in grid station and other communication units.

E. High Transmission Efficiency and Asset Utilization

To increase the transmission efficiency, transmission towers should be monitored continuously. In addition, protection against lightening issues results in blackouts. Methods to prevent lightening strokes are explained in. Similarly to maximize the utilization of T.Ls and TG, capacity use of FACTS and HVDC devices for flexible control over long distances are helpful. Methods to avoid arching, switching bounces and efficient transformation of voltage levels using solid state devices as the replacement of conventional circuit breakers, relays and transformers can be studied.

Question No 2.

There are many causes of power failures in an electricity network. Examples of these causes include faults at power stations, damage to electric transmission lines, substations or other parts of the distribution system, a short circuit, cascading failure, fuse or circuit breaker operation.

i. Discuss the typical sequence of steps seen in large power system blackouts. Explain with the help of example that how a self-healing grid can arrest the sequence and prevent such blackouts.

ii. Consider the example of a disastrous blackouts in Pakistan and Explain how this typical sequence

Answer: i)

Blackouts of power systems occur in transmission networks (TNs) as the result of dangerous emergency overloading. These are followed by cascade tripping of transmission lines and power plants and, finally, by collapse of a power system. A cascade-type emergency causing a power system (PS) blackout is a problem of great concern. Such emergency extends over large territories, leaving without electricity hundreds of thousands or even millions consumers creating serious disturbance of national economy activities and inflicting heavy losses on it as well as bringing the threat to the equipment. Thus, for example, during the energy collapse of 1965 in the USA the emergency outage of a thermal power station occurred, which resulted in damage of a 1000MW turbine.

Cascade processes develop very fast, with a speed that exceeds many times the capability of personnel to perceive the situation and think it over. As a result, people can interfere in the process only in the post-emergency stage in order to restore the operating condition. Therefore, for the power systems it is necessary to have emergency protection automatics whose role would be to prevent the beginning of a cascade process and its progress.

THE PROCESSES CAUSING COLLAPSE OF A Power Systems AND THE RESTORATION OF NORMAL OPERATING CONDITION

A. Initiation of a cascade process in the course of PS blackout

For example, when analyzing the proceeding of major blackouts, we have revealed that, at the emergency beginning, the line overloading with active power flows that owes to the fault of an important element gives rise to a cascade process and a blackout of the power system (see Fig. 1)

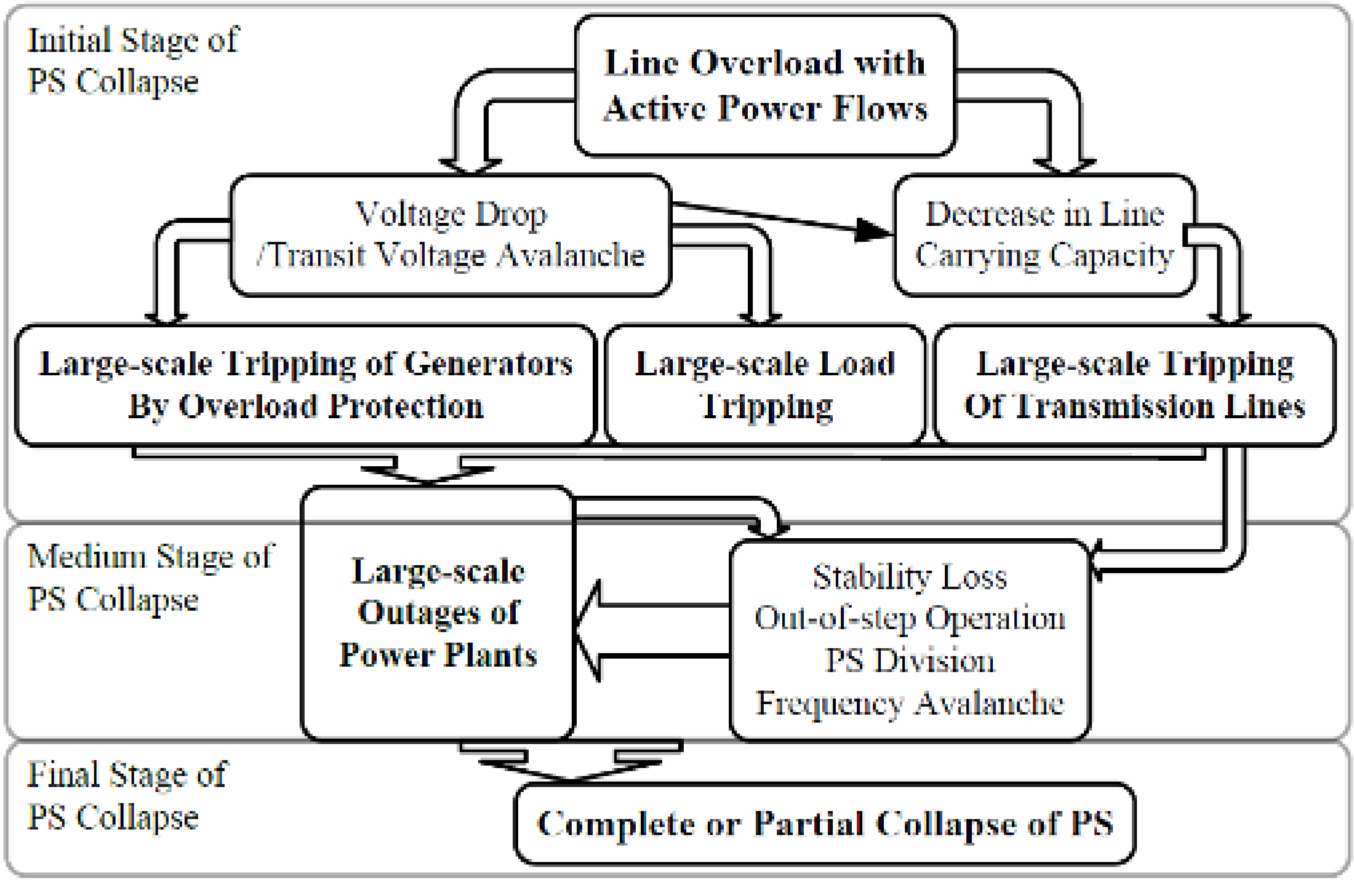

Fig. 1. Stages of a power system blackout

The process is expressed as follows.

- Large-scale tripping of the lines resulting from ground faults, with remaining damage inflicted by sagging of the line wires;
- Large-scale tripping of the generators from overloading protection caused by the transit voltage avalanche;
- Large-scale tripping of the load caused by the transit voltage avalanche. Such cascade processes are the main cause of outages of power plants in the stage of emergency beginning, before the loss of stability occurs.

B. Large-scale tripping of the lines

With overloading, the temperature of wires increases, which can become even higher when the weather is hot and sunny. In turn, with the temperature of wires increasing their sagging becomes greater. As the distance to ground decreases the wires turn out to be laying on it thus causing ground faults. A large-scale tripping of the lines start, at which the faults remain and the automatic re-closing [ARC] is unsuccessful.

C. Transit voltage avalanche and its impact on the system's functioning

1) Types of the voltage avalanche

The voltage avalanches are stationary emergency operating conditions at which the voltage considerably decreases. Three types of the voltage avalanche can be distinguished:

- *The voltage avalanche of a load center*, which occurs at local load centers in the cases when the reactive power source equivalent to the node possesses a negative voltage dependence of reactive power (the power decreases with decreasing voltage). The reactive power balance in the node is stabilized by the load shedding automatics responding to indicators of a voltage fall.
- *The accompanying voltage avalanche*, which takes place simultaneously with the frequency fall in the active-power-deficient part of a power system, with this part separating in the emergency order. The voltage fall is in this case limited by the operation of load shedding automatics [LSA] simultaneously with the frequency stabilization. Obviously, this should be insensitive to the voltage deviations.
- *The transit voltage avalanche*, which establishes when the voltage is decreasing along the transmission network transit as the result of its emergency overloading. Such an avalanche spreads to a wide territory where many generating stations are operating.

2) Large-scale tripping of generators

On the one hand the voltage instantaneously drops, in an avalanche-wise way, to the values to which the excitation regulators of generators at the nearby generating stations respond by increasing the excitation current above the rated values.

3) Large-scale load tripping

On the other hand, the voltage drop affects the load. It is known that low voltage causes changes in consumption in compliance with static characteristics of the load. In addition, since a significant portion of the load is connected through magnetic starters, these latter begin disconnect in quantities, and the corresponding load is lost. However, the load required for operation of thermal stations should be not less than 40% of the rated capacity of operating equipment. Therefore, the load tripping can be a serious obstacle to the operation of generating stations thus promoting the disruption of the operating condition. From the mentioned above it is clear that the technical measures meant for avoidance of cascade processes must be urgently realized, with the main purpose to keep the lines and power plants in operation. Otherwise the loss of stability and the separation of a power system in most disadvantageous places and with serious complications are inevitable. The measures should be radical, as daring and simple as possible, directed to the liquidation of the line overloading. If the maximum possible number of generating stations is being kept in operation the parts of a power system will be reconnected automatically within few seconds.

D. Restoration of the normal work of a power system

The restoration of PS functioning can proceed in two ways:

- with personnel involvement, or
- by self-restoration, without personnel participation.

In the former case, after a severe cascade emergency against which no universal means exist, the restoration of a power system is complicated owing to the absence of voltage in large territories. The operations for which electric energy sources are required cannot be performed. For the power stations to resume operation it is necessary to start the technological processes that consume a relatively large power for their auxiliaries' services. If in the process of a power system's blackout there occurred separation of some regions with formation of "islands "where generating stations are still under operation, from these stations energy is supplied to the idle-standing stations putting them into operation step-by-step. In total, to restore the functioning of a power system approximately two days are needed. Based on the analysis and their own experience the authors can state that, using advanced and well-thought over anti-emergency automatics, it is possible to avoid a blackout in a PS, with the emergency elimination within about two minutes without personnel participation.

Power systems are the most complex systems and have great importance in modern life. They have direct impacts on the modernization, economic, political and social aspects. To operate such systems in a stable mode, several control and protection techniques are required. However, modern systems are equipped with several protection schemes with the aim of avoiding the unpredicted events and power outages, power systems are still encountering emergency and mal-operation situations. The most severe emergencies put the whole or at least a part of the system in danger. If the emergency is not well managed; the power system is likely to have cascading failures that might lead to a blackout. Due to the consequences, many countries around the world have research and expert teams who work to avoid blackouts on their systems. The ability of power systems to maintain stability and to ensure continuous supply of electrical power to customers in the event of a disturbance is of critical importance. As the power system is spread over large geographic regions, the probability of facing different types of faults and failures is high. Unfortunately, unpredictable faults and cascading events usually lead to a blackout which might affect modern life. Figure 2. Shows State-of-the-art flow chart of power systems blackout and cascading events: motivations and challenges.

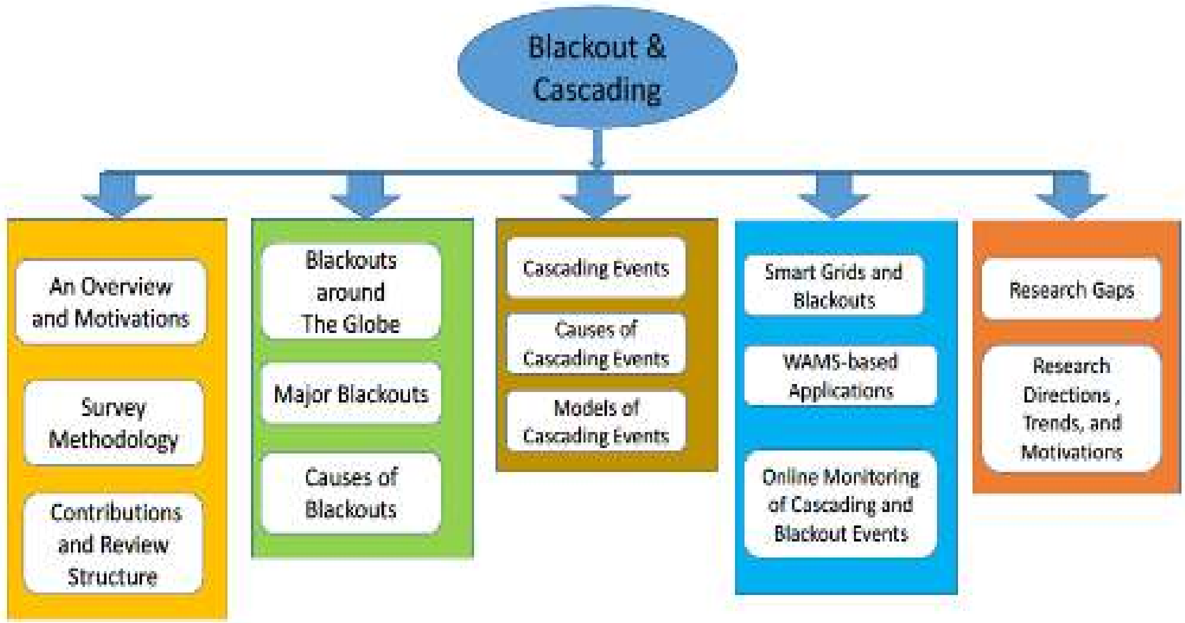

Figure 2. State-of-the-art flow chart of power systems blackout and cascading events: motivations and challenges.

Answer 2 (ii)

Energy Crisis in Pakistan is one of the severe challenges the country is facing today. Electricity, gas, water, fuel is essential part of our daily life and its outage has severely affected the economy and overall living of ours. Thousands have lost their jobs, businesses; our daily life has become miserable. Pakistan is currently facing up to 18 hours of electricity outage a day, is expected to face more if not dealt with in time.

1) Blackouts in Pakistan:

An energy crisis is any great shortfall (or price rise) in the supply of energy resources to an economy. It usually refers to the shortage of oil and additionally to electricity or other natural resources. The crisis often has effects on the rest of the economy, with many recessions being caused by an energy crisis in some form. In particular, the production costs of electricity rise, which raises manufacturing costs. For the consumer, the price of gasoline (petrol) and diesel for cars and other vehicles rises, leading to reduced consumer confidence and spending, higher transportation costs and general price rising. Energy resources have depleted! Whatever resources are available are simply too expensive to buy or already acquired by countries which had planned and acted long time ago. Delayed efforts in the exploration sector have not been able to find sufficient amounts of energy resources. Nations of the world which have their own reserves are not supplying energy resources anymore; only the old contracts made decades ago are active. Airplanes, trains, cars, motorbikes, buses and trucks, all modes of transportation are coming to a standstill. Many industries have closed due to insufficient power supply. Price of oil has gone above the ceiling. At domestic level, alternate methods like solar, biogas and other methods are being tried for mere survival.

The above is a likely scenario of Pakistan and around the globe after 25 years. A pessimistic view, but realistic enough to think about and plan for the future. But are we doing anything about it? Let's have a look at the current energy situation of Pakistan and the world. Pakistan's economy is performing at a very high note with GDP growing at an exceptional rate, touching 8.35% in 2004-05. In its history of 58 years, there has been only a few golden years where the economy grew above 7%. This year official expectations are that GDP growth rate will be around 6.5 – 7.0%. For the coming years, the government is targeting GDP growth rate above 6%. With economy growing at such a pace, the energy requirements are likely to increase with a similar rate.

The energy consumption is expected to grow at double digit if the overall economy sustains the targeted GDP growth rate of 6% by the government. Pakistan's energy requirements are expected to double in the next few years, and our energy requirements by 2015 is likely to cross 120MTOE. By 2030, the nation's requirement will be 7 times the current requirement reaching 361MTOE. Pakistan's energy requirements are fulfilled with more than 80% of energy resources through imports. On the other hand, international oil prices have not only broken all records but are touching new highs, with every news directly or indirectly affecting the black gold industry. Moreover, speculators all around the world expect oil prices to touch $100 per barrel in medium term. With concerns over Iran's nuclear program, terrorist issues in Nigeria and high economic growth in China & India and their ever rising energy requirements, oil prices don't see any another way but to shoot upwards.

One of the major problems facing the new government, the energy crisis, is intense, costly and multi-dimensional. The infuriating electricity and gas disruptions and soaring fuel prices in turn pushing the cost of living have made life difficult for people. The even before it took office the new government was greeted with two jumps in fuel prices, accounting for a 15% rise in two weeks. Meanwhile, crude oil prices have been registering all-time-highs, shooting 40% in the past year. The undeniable reality is that that this global spike will somehow have to be accommodated in energy prices in Pakistan.

There is no quick solution to electricity shortage and the trend of surging prices is irreversible. There is very little the new government can do on this in the immediate term. At best, the problem can be prevented from aggravating until a sustainable solution is struck. Tough decisions will have to be made, and executed with commitment.

The starting point of any remedial efforts should be an acknowledgement of the fact that the crisis is a self-inflicted one. It cannot be denied that something has been wrong down the line that caused this crisis. The country has nearly gone energy bankrupt while a total disaster appears to be round the corner unless pragmatism is shown. It is also important that lessons be learnt from the past mistakes on part of relevant circles. The crisis is still addressable as long as there is due vision and devotion.

One of the major limitations that have hindered energy prosperity in the country is short-sightedness. There has not been a meaningful and coherent energy policy in place over this period. The approach has been "project-oriented," rather than "goal-oriented." Almost every regime has dealt with energy on an ad hoc basis. Long-term and sustainable planning of energy have been an alien concept. The reason is fairly simple; energy projects usually require huge investments and commitment, making them undesirable to any regime. The attitude of delaying new projects, as far as possible, has been the common practice and is in fact the recipe of the present crises. In doing so, when things start getting out of control, haphazard and quick-fix measures are sought.

A typical example is the Independent Power Producers (IPPs) saga of the 1990s. In an attempt to avert an approaching energy crisis, as a result of negligible capacity addition during the 1980s and the early 1990s, the regime in 1993-94 decided to go for thermal generation through the IPPs. Undoubtedly, the IPPs provided a very healthy contribution at the supply end, enhancing power generation capacity by more than 5000MW. Nevertheless, this power addition cost the country a fortune – apart from the controversial tariff structure, the move was against the spirit of energy sustainability and security for the country. The fact that the IPPs were set up at the terms of the investors suggest that it was a move made in panic.

The last few years provide a perfect example of failure to make a timely response to the growing energy needs. A threefold increase in energy demand over the last two decades has been responded to with an ill-proportioned increment at the supply end. Consequently, with the advent of 2008 the gap between demand and supply grew to 4,500MW indicating a 40% deficit of electricity. The prevalent energy crisis has not appeared overnight – the omens were evident for a number of years but the authorities failed to react in time. Senior WAPDA officials claim that in 2002 the government was officially warned about the approaching electricity crisis and was asked to take immediate measures to enhance generation capacity. The timely warning failed to receive any appreciation. The attitude of the relevant authorities has thus indirectly contributed to the growth of the dire crisis. Another example worth quoting here is that of the 969MW Neelam-Jehlum hydroelectric project. It was to be constructed in 2003 at a cost of $1.5 billion. It got abandoned until the present power crises intensified towards the end of 2007. The revised estimate is around $2.25 billion. The delay is costing the country a fortune – an extra $750 million in terms of project cost, apart from enormous monetary dents inflicted by the five-year delay. It is also noteworthy that WAPDA has traditionally pursued the major projects of national interest but failed to get the due positive response from the policy- and decision- makers. Interestingly, WAPDA plays the role of a scapegoat, because the common man blames WAPDA for his sufferings.

It is also important to plant relevant and qualified people at the key policy and decision making positions. Quite often, these positions are offered to utterly irrelevant, ill-qualified and incompetent people. The track record suggests that energy offices are amongst the most coveted ones in any regime, simply because they are considered to be the most lucrative ones. There are examples when undergraduate and utterly irrelevant people have been appointed to run energy offices. There are also cases when the crucial positions have been used as incentives during political bargaining. The unhealthy attitude towards sensitive energy positions is enough to explain how the field of energy has been traditionally toyed with.

Another aspect of the bankrupt policies is politicization of projects of national interest. The paramount example is that of Kalabagh Dam. It has been politicized to such an extent that its orchestration now appears to be next to impossible. Evidences suggest that the issue has been used to serve the vested interest of regimes and certain political and ethnical forces. With the emerging post-election sense of national reconciliation on the political arena, it is expected that such projects would be looked into with cool heads. It is time to move on. The technical issues, if there be any, have to be addressed on the drawing board, rather in processions. It has to be realized that the delay in project has not only made the country suffer but also people that come from all provinces.

In order to tackle the existing crisis and ensure a prosperous energy future, the backbone of the future energy policies would have to be reliance on domestic resources (hydropower, coal and solar and wind energy) and energy conservation. Decisions on energy projects should revolve around national interest rather than naÃ¯ve political and personal gains. Energy offices should be run by qualified, committed and deserving people equipped with due mandate. Relevant ministries and departments should also be overhauled.

2) Methods for Generating Hydel Energy

Two methods are normally used:

- **Dams**

In case of Dams the water flow is restricted by the making a huge storage device and the head of water is increased, the water then is allowing to flow by means of gates and pass through the turbine, the head of reservoir level is maintained to provide uniform power and the water stored in the season additionally is used for irrigation purpose in the dry season.

- **Run of the river projects**

In the run of river project, the water is diverted through the tunnel and once it gains the head allowed to fall and pass through the turbine and back too river. The water in these projects is continuously flowing and not being stored.

Geographical situation is paramount importance in choosing the suitable site for the hydel project and it evolves a very serious time and money consuming study.

- **Feasibility Study**

Once a site is located further detailed feasibility study is required before preceding any serious effort to start the work.

The feasibility study should include following field work.

1: Detailed Mapping of the area.

2: Topographic study of the area.

3: seismic refraction study.

4: River flow data.

5: Weather data contain Temperature, Pressures, and Rain Humidity.

6: Water sampling and testing.

7: Environmental study.

8: Social impact.

9: Identification of stake holders of the area.

3) Pakistan Major Dams

- **Warsak Dam**

The gigantic multi-purpose Warsak Dam is situated 30 kms north-west of Peshawar in the heart of tribal territory. It has a total generating capacity of 240,000 kW and will eventually serve to irrigate 110,000 acres of land.

- **Mangla Dam**

World's third largest earth-filled dam is only 115 km south-east of Rawalpindi. One has to turn left from Dina Town and the dam on river Jhelum is about 14 km to the east. The dam is 3,353 meters long and 116 meters high above the river bed. It is designed to store 5.88 MAF water and also used for power generation. In the centre of the dam there is a Gakkhar Fort from where one can have a panoramic view of the lake. For permit to visit the dam, please contact PRO, WAPDA, and Mangla. A NOC from the Ministry of Interior is required for foreigners only.

- **Tarbela Dam**

The world's largest earth-filled dam on one of the world's most important rivers – the Indus – is 103 km from Rawalpindi. The dam was completed in 1976 at a cost of Rs.18.5 billion. Over 15,000 Pakistani and 800 foreign workers and engineers worked during its construction. It is the biggest hydel power station in Pakistan having a capacity of generating 3,478 MW of electricity. Its reservoir is 97 km long with a depth of 137 meters while total area of the lake is 260 sq.km. Permits are required for visiting the Dam. Please contact Public Relations Officer (PRO), Water and Power Development Authority (WAPDA), Tarbela (Tel: 051-568941-2). A No-Objection Certificate (NOC) from the Ministry of Interior (Shaheed-e-Millat Sectt.), Islamabad is also required for foreign visitors.

4) Hydel Energy and its Crisis in Pakistan

The energy crisis starts from 1990 and still Pakistan is in the crisis of these all as before. The latest and perhaps the most troublesome crisis faced by the Pakistani nation these days is the shortage in supply of electricity. The country is facing a huge electric power crisis these days. Though it has been more than a year since when the country is facing this crisis, but till now no proper solution has been made to this problem neither any proper planning has come into existence since the symptoms and begging of this short supply of electricity. While rolling blackouts or load shedding as it is locally known has always been a staple of daily life in Pakistan, the problem has become acute in the last couple of years.

This crisis appears insurmountable in the near or even long-term future, unless proper understanding and correct implementation is undertaken on priority basis. At present total power production capacity in the country is about 19,500 MW, out of which Hydel Power is only 6,500 MW, balance of 13,000 MW is thermal either using Natural Gas or Furnace Oil. Small capacity of 450 MW is Nuclear and only 150 MW is through coal. It is very important to understand the consequence of the prevailing situation. Current price of furnace oil is about Rs.49000 per ton, which amounts up to Rs.49/- per kg. On an average one kg of furnace oil produces 3.8 kWh of electricity. Thus, the cost of furnace oil for generating one unit of electricity is about Rs.13. On top of this the fixed cost of a thermal plant works out to be about Rs.3 per unit. Therefore, one unit (kWh) of the electricity produced by all thermal plants using furnace oil is Rs.16 per unit.

According to WAPDA/IPP (Independent Power Producers) agreement, the private power producers will charge WAPDA the actual fuel cost for which they have a direct contract with PSO. As we all know that WAPDA tariff charged from the consumers is about Rs.5 per unit (kWh).

The production cost of furnace oil electricity is Rs.16 per unit, add to it the transmission, distribution cost (including loses), “the total cost of such electricity works out to approximately Rs.22 per kWh. The difference between WAPDA tariff and the furnace oil electricity is Rs.17 per kWh.” It is estimated that the country consumes at least 25 billion units of electricity produced annually through furnace oil, which amounts to the total deficit of Rs.425 Billion. If WAPDA has to balance its books it would require a subsidy of Rs.425 Billion. This deficit is somewhat reduced due to cheap power produced through hydel energy and natural gas, but the deficit cannot change substantially, unless bulk of electricity is produced through hydel energy. Obviously, a deficit of Rs.300-350 Billion cannot be sustained, the government does not have resources to pay such a huge subsidy, and it is also not feasible to increase the power tariff very much. Therefore, the power crisis is far greater than what is being perceived. In the absence of extremely heavy subsidy, WAPDA is delaying payments to IPPs and also to the oil companies. The result is that IPPs are now producing much less electricity than their capacity.

5) Thermal energy

Thermal energy is the thermal type of energy, with all known history available, wood always used for heating and cooking. In 2nd world war fossils fuels entered in the form of coal to get energy. Until liquid fuels were discovered and because of them convinces of transportation they took over as major of energy source.

Once the steam engines were invented then the coal or liquid fuels was burnt in the in boilers and heat producers steam which is used to drive an electrical generator, or any other mechanical devices. Rudolph diesel invention of diesel engine revolution the energy concept and today we see sine the majority of machine moving on diesel engines. Diesel engines can be 2 stroke or 4 stroke type. They can be in line or arranged in V or even W shape. They can be single acting or double acting. Another method of converting thermal energy to mechanical energy is by the gas turbines. Turbines are also used to run by steam or hot gases which are produced by igniting fuel.

The choice of gen sets strictly depends on the requirement of client, before ordering a power plant following points to be considered:

Expected demand of the power

Type of fuel required

Space available for the power plant

Availability of gun sets

Availability of local service back up and stock of parts

Price is paramount importance and hidden expenses should be locked carefully.

The major manufacturers and suppliers of gen sets based on internal combustion engines are given below:

- Man
- Wartsila
- Caterpillar
- Jen bacher
- Waukesha
- Mitsubishi
- Detroit diesel
- Rolls Royce

Internal combustion engines can obtain 30_50% thermal efficiency. It means that around 50%energy is wasted in the form of exhaust gases, cooling system and radiations. Therefore, for larger plants heat recovery system are utilized.

6) Crisis of Thermal Energy

The oil crisis facing the world is not about supply or about the increase in demand. It is about the speculators who are pumping huge amounts of money into forecasting a serious shortage ahead. Not now but in the future. And that the prices will escalate enough for them to make a killing. If one looks at the real picture, there is no shortage of oil, there has been no shutdown of any major producer, nor has there been a sudden jump in the import from any large consumer. The Chinese import for their industrialization is not more than 10 percent annually. This is certainly not enough for the huge jump in the world crude rates. This jump is matched by the phenomenal profits of the oil companies and of course the oil producing countries. The thirst for profits of the oil traders has benefited the oil producers -Iran being a major beneficiary. The US government must be wondering at the irony of this windfall benefiting a prime enemy of American and Israeli interests at the cost of millions of innocent citizens of the US and Europe, engineered by the greasy gnomes of the oil trade. There is no threat of an oil embargo, nor of a war, it is just pure speculation, funded by the huge mountains of American and European cashes at the disposal of the Sources the Oil trade. They stand to make a killing at the expense of hapless citizens of the world. As I had written in an earlier piece as far back as 2005, when an attack on Iran was imminent, that the rise in oil at 100 $ a barrel would impact on the food prices has proved prophetic with the current sky high prices of bread in Europe and America. In the mean time we poor Pakistanis are suffering with 50 percent living below the poverty line, and many more being pushed under thanks to the current oil crisis which has managed to create tsunami that is a threat worldwide, with no remedy in sight. Electricity riots are already a common sight but the frequency of breadlines breaking into riots is increasing daily, not just in Somalia but in parts of the third world where we thought wheat was never in critical shortage. The riots in Pakistan are for two reasons. Firstly, the price a worldwide phenomenon and second a physical shortage due mainly to incompetence in the many layers of our government.

7) Looming Energy Crisis in Pakistan

Energy costs, from where they stand now, could rise by more than 50 percent in the next few years. The cost of power on this scale would be difficult to manage by most emerging economies all oil-consuming countries, particularly the third world have suffered due to the consistently rising demand-driven cost of energy.

From 2004 onwards, the price of oil started soaring in the international market, and for the first time in October 2004, oil prices crossed the benchmark of US$ 50 per barrel. It continued to fluctuate but kept moving up each year and in 2007 briefly crossed US$ 100 per barrel. For the past few days it has been hovering at US$ 103 plus per.

The primary power system of WAPDA is operated at 500 kV and 220 kV voltage levels in an interconnected manner while the secondary regional systems within each load center are operated at 132 kV and 66 kV voltage levels. The salient characteristics of WAPDA power system are as below:

- Longitudinal system network topology with bulk hydro generation in northern part and bulk thermal generation from mid-country to southern part of the network
- Big load centers, e.g., Lahore, Gatti etc. remote from bulk generation resources
- Seasonal variation in dispatch of hydro generation and accordingly reversal in direction of power flows on 500kV lines in northern part of system
-

8) ANALYSES TO INVESTIGATE SYSTEM COLLAPSE

In order to investigate system collapse of 24"September 2006 Power System Simulator for Engineering (PSS/E) software package were used as:

- Power flow simulations to analyze system performance under steady state conditions.
- Time domain simulations to analyze system performance under dynamic conditions.
- Eigenvalue/Modal analysis to assess system damping or oscillatory behaviour.

In the existing power network of WAPDA, three uncompensated 500 kV transmission lines, i.e., two from G.Brotha hydro power plant (HPP) to Gatti, each line 310 km long, and one line from G. Brotha HPP to Lahore, 346 km long, are used to transfer bulk power during summer season from northern HPPs of Tarbela and G. Brotha to big load centers of Lahore and Faisalabad (Gatti) and further onwards. In addition, fourth 500 kV transmission line is also under construction from Rewat to Lahore.

9) System Condition prior to Collapse

It was a typical summer day on 24"September 2006 and the total system demand of WAPDA, prior to system collapse at 1343 hrs., was 11160 MW and the northern hydro plants were meeting 53% of total system demand. Tarbela and G. Brotha HPPs, that mainly feed 500 kV system, were generating 3688MW and 1000MW respectively while Mangla HPP, that mainly feed 220 kV network, was generating 800 MW. However, the 500kV transmission line from G.

Brotha HPP to Lahore was shut down from 0600 to 1400 hrs. on 24th September 2006 for maintenance work.

With the above generation dispatch pattern, the remaining two 500 kV transmission lines from Ghazi Brotha to Gatti were loaded to 1110 MW and 1129 MW (very close to their stability limits), and there was no capacity margin on these lines to allow additional power to flow safely. Tarbela and G. Brotha HPPs were also feeding Rewat 500 kV substation having 2x450MVA, 500/220kV transformers through direct 500 kV lines. Moreover, 167 MW power was flowing from ISPR to Rewat on 220 kV D/C line. As a result, the transformers at Rewat substation were loaded 94% to their capacity before disturbance and after feeding their nearby areas of Rewat and Islamabad, were supplying more than 600 MW to the load centers of Gujranwla and Lahore in its south through 220 kV transmission network, in association with generation of Mangla HPP. In addition, the voltages at the receiving ends of Gatti and Lahore were 1.03 and 1.01 p.u. respectively before initiation of disturbance.

Question 3

The communication network is backbone of a smart grid and is characterized by the coverage in smaller areas like homes and buildings, coverage over medium areas ranging from few hundred meters to about a kilometer and coverage over longer distances. Explain in details the type of networks used to create smart grid communication network. Also discuss what type of communications can be that are necessary in smart grid environment.

Answer:

Communication Technologies of Smart Grid

1) Wireline Communication Technologies

Wireline communication is always preferred due to the reliability and less prone to interference. All the communication technologies both in terms of wireline and wireless are shown in Figure 1 and Figure 2. Modern technological trends such as Software Defined Networking (SDN), Internet of Things (IoT), New Radio (NR), and upcoming Fifth Generation (5 G) cellular networks based deployment of SGs.

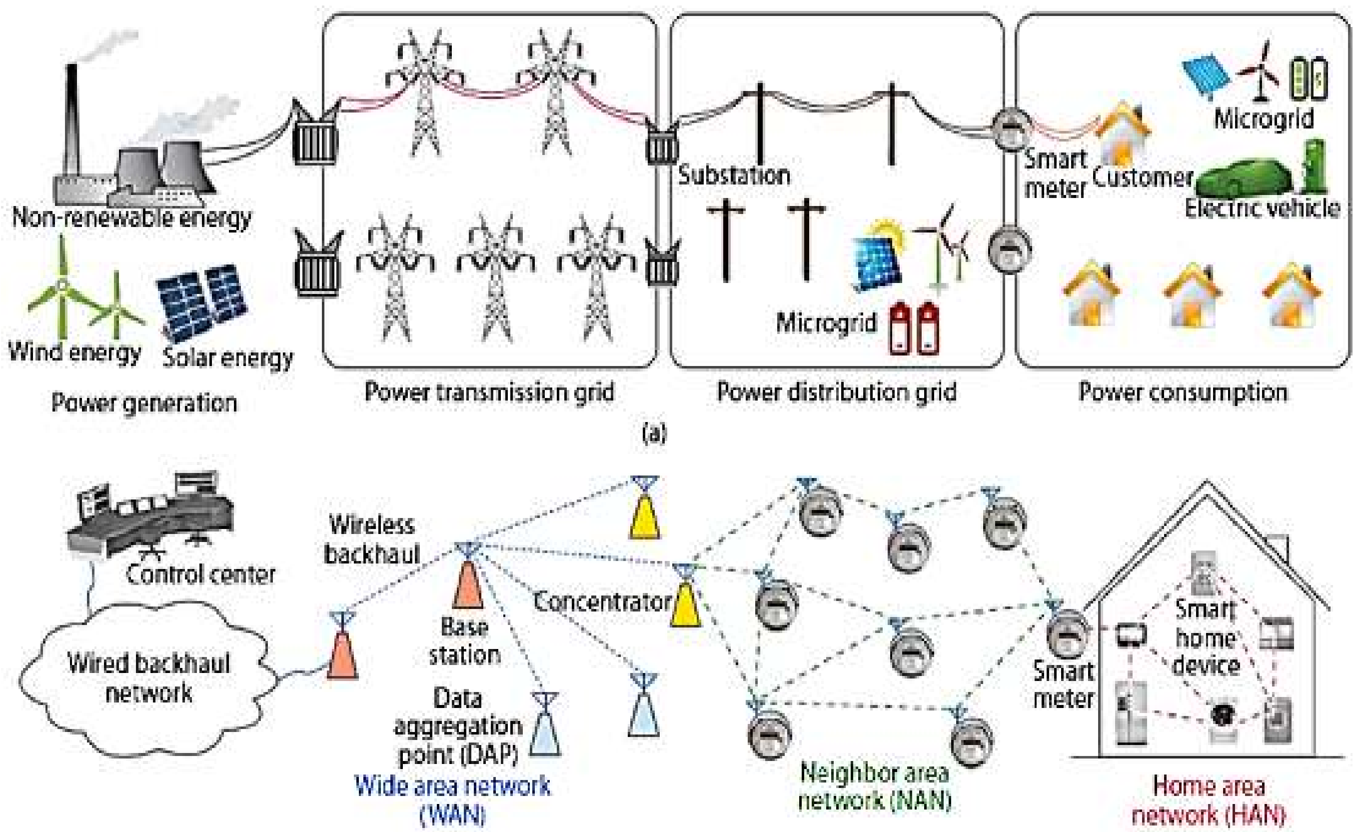

Figure 1. Complete Layered Architecture of SG

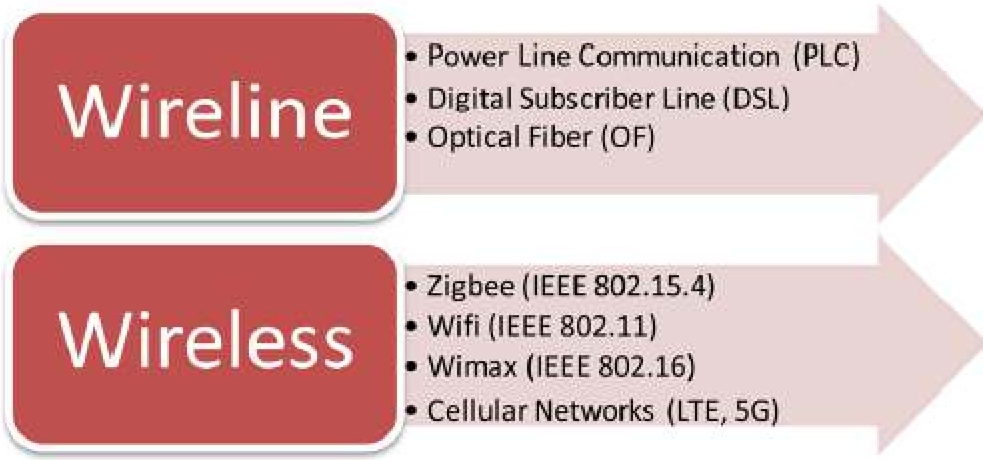

Figure 2. Communication Technologies of Smart Grid.

1.1. Digital Subscriber Line (DSL)

Digital Subscriber Line (DSL) provides 10 Mbps to 10 Gbps data rate over the conventional telephone line. Asymmetric DSL (ADSL) provides 8 Mbps, ADSL2+ provides 24 Mbps and very-high-bit-rate DSL (VDSL) provides 52 Mbps downstream data rate over copper wires.

1.2. Power Line Communication (PLC)

Power Line Communication (PLC) is a widely used wireline communication technology for the SG. PLC face lots of technical challenges such as unpredicted propagation features and electromagnetic interference due to transformers and of transmission and distribution power lines. Cater to these issues, there are several PLC technologies are in use. Narrowband PLC (NB-PLC) provides 1 bps to 500 Kbps data rate at 500 kHz frequency whereas broadband PLC (BB-PLC) provides up to 200 Mbps data rate at 2 MHz to 30 MHz frequency.

NB-PLC and BB-PLC are based on two-way communication and are capable of handling and identifying equipment faults by delivering utility application specific high-speed real-time data. These technologies are preferable on the power grid distribution side by participating in and supporting distributed generation (DG), micro grids and consumer participation. PLCs are providing point to point (P2P) communication b/w transformer substation on a medium voltage (MV) distribution and are configured to provide point to multipoint connectivity on a low voltage (LV) b/w meters and transformers near to the home, building and industry consumers.

1.3. Optical Fiber (OF)

Optical fiber guided media communication is a globally deployed wireline communication infrastructure and is a great choice as a backbone network for SGs services like Video traffic with very low latency at very high speed. It provides a maximum of 10 Gbps data rate with a single wavelength and 40 Gbps to 1600 Gbps with wavelength division multiplexing

(WDM). optical/electric transducers used in optical communication is an ideal choice for SG due to excellent sensing and measurement capabilities of the current and voltage values of electrical power.

2) Wireless Communication Technologies

Wireless communication technologies are always best suitable due to ease of implementation and less installation cost as a network to work with the smart grid. However wireless signals may have more attenuation and interference as that of wireline signals due to the direct impact of transmission and environmental factors, so these signals provide reliable communication over shorter distance with less data rate and bandwidth, also they always less secure and have serious privacy Concerns.

2.1. Zigbee (IEEE 802.15.4)

ZigBee is IEEE 802.15.4 standard based on wireless mesh topology network for a cost-effective, low power and well-organized solution for wireless communications. ZigBee offers less data rate in personal area networks (PANs) such as HAN. This wireless technology provides numerous applications such as automation, control, messaging and remote monitoring of consumer electronics/ home/building as well as healthcare, etc. It uses direct sequence spread spectrum(DSSS) to provide communication between linked devices in a very less power. It provides 250 kbps data rate over the 2.4 GHz unlicensed band, 40 kbps over 915 MHz band and 20 kbps over 868 MHz licensed band per channel. It supports 10 - 75 meters Point to point (P2P), 30 meters indoor and ever more in a mesh network. Mesh network may have multiple links to route data packets from source to destination and the links are dynamically updated and optimized by the network devices. These characteristics of the mesh network make it more scalable, stable and fault-tolerant network of wireless nodes.

2.2. Wi-Fi (IEEE 802.11)

Wireless Fidelity (Wi-Fi) is very popular and mature wireless local area network(WLAN) technology adopted by the home applications worldwide. It’s operated in an unlicensed band and is subjected to interference because several other technologies are also sharing the same spectrum. Innovations in technologies are moving Wi-Fi towards power sketchy and reduced cost communication. It’s very preferable technology for HAN architecture. However, citywide infrastructure of Wi-Fi will also support HAN, NAN and WAN applications. The typical data rate of Wi-Fi is 1 - 150 Mbps over the distance of 20 to 100 meters.

2.3. WiMAX (IEEE 802.16)

WiMAX can transport the application’s data of terminal devices enabled with ZigBee or Wi-Fi wireless communication technologies in NAN and WAN networks. Smart meters (SMs) generated data is transferred from concentrators to the backend connected WiMAX base stations. It’s a good choice for increased data to be transported via WiMAX base stations in a less cost making promising to deploy advanced real-time applications control with wider bandwidths. It also supports distributed automation, control, monitoring, management, fault identification oriented advanced SG applications. The typical data rate of WiMAX is 288.8 Mbps downlink and 72.2 Mbps uplink over the distance of 5 - 100 Kilometers.

2.4. Cellular/Mobile Networks

Cellular networks are most suitable wireless technology in WAN communication architecture for the transportations between SMs and the Utility companies due to its stable infrastructure. Cellular networks are offering numerous wider area services to the SG applications in a very affordable way. Emergent of third-generation (3 G) and LTE wireless communication technologies to the cellular networks provide much higher data rates in NAN and WAN networks. Several grid assets such as circuit breakers (CBs), Sensors, transformers, remote terminal units (RTUs) and substations are connected to the nearly suitable centers via fiber connections, making it ideal for the SG applications to deploy in a short time frame without increasing the upfront cost of deployment. Typical data rate of Universal Mobile Telecommunications System (UMTS) example of 3 G cellular is 2.048 Mbps over the distance of up to 120 Kilometers and LTE is 300 Mbps downlink and 75 Mbps uplink over the distance of 100 Kilometers.

Question 4

a. How does the smart meters' architecture differ from the conventional energy meters in smart grid environment?
b. Comprehensively discuss the network in smart meter system by elaborating communication and electrical interfaces.
c. Discuss the major design issues of a smart meter system.
d. What are the advantages of load scheduling in smart grid considering both the PPs, consumers and grid operations? Discuss in detail

Answer: 4 (a)

Conventional Vs Smart Meters.

Some countries and organizations are modernizing their utility grids by replacing their traditional electromechanical electricity meters with digital electricity meters, which measure and record electricity use every hour. For traditional electricity meters: (a) No data storage, (b) A meter reader physically comes to the customer's home or business to record the information and send it to the metering company, (c) If access cannot be gained to the meter, this may result in estimated bills, (d) Electricity use is tracked by either waiting for customer's monthly or quarterly bill or manually reading customer's household meter by oneself, (e) No outage detection, as distribution companies cannot react quickly to interruptions in the supply, (f) Connections and disconnections must be done manually.

For smart electricity meters: (a) Data storage, stores electricity consumed every half of an hour, (b) Data is automatically transmitted to the metering company, (c) Digital data of energy consumption and TOU are provided in near real time, (d) Automated outage detection enable distribution companies to restore power quicker than traditional electricity metering, (e) Connections and disconnections are faster, because they are managed remotely. Traditional electricity meters only show the quantity of electricity consumed since someone (meter reader) last read the meter. Using smart electricity metering, there is: (a) An increase in accuracy, features, visibility, privacy and security, (b) Fewer human errors and there will be no estimated bills. Smart metering helps: (a) Electric utilities eliminate manual monthly meter readings, (b) Avoid capital expenses of building new power plants, (c) Optimize income with existing resources, (d) Dynamic pricing, which raises or lowers the cost of electricity based on demand,

(e) Power resources use more efficiently. Smart metering helps electricity consumers: (a) Adjust their habits and lower electricity bills, (b) Reduce the number of blackouts and system-wide electricity failures, (c) Obtain greater and more detailed feedback on electricity usage. Smart metering helps the environment: (a) Reduce the need for new power plants, which produce greenhouse gases (GHG) that substantially creates pollution resulting in health risks, and (b) Curb existing GHG emissions from existing power plants. Figure 1 shows block diagram of Traditional Vs Smart electricity metering Systems While Figure 2 shows Traditional Vs Smart Electricity Meters.

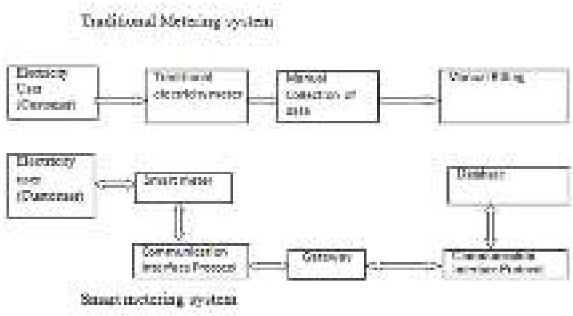

Figure 1. Block Diagram of Traditional Vs Smart electricity metering Systems

Figure 2. Traditional Vs Smart Electricity Meters

Although smart meters have many advantages and benefits, they present some challenges and disadvantages as, smart meters have shorter life expectancy (5 to 7 years), compared to traditional meters (20 to 30 or 40 years).

The disadvantages for utility grid companies include
(a) Costs in personnel training, equipment
development and production to transition into new technologies and new sets of processes,
(b) Managing negative public reactions and acquiring customer acceptance of the new meters,
(c) Making long-term financial commitments to the new metering technology and the related software involved, (d) Managing, storing and analyzing the vast quantities of metering data collected,
(e) Ensuring the security and privacy of metering data.

The disadvantages smart metering for consumers include

(a) It is difficult to ascertain if the new meter is accurate,
(b) There is additional fee for the installation of the new meter.

When customers use smart electricity metering systems, there are options in the installation of smart electricity monitoring systems, which help them to control their electricity usage rates. Whereas nobody would wake up in the morning and think, 'I want to use more energy (electricity) than my neighbor today', but inducing people to actually reduce their energy consumption is still very difficult.

For smart electrical energy monitoring systems to function as expected, it is preferable to:

(a) Make electrical energy visible to consumers,

(b) Utilize the full range of information delivery services available to consumers such as point of consumption and mobile devices to monitor energy consumption

(c) Push the boundaries of technology design through participatory studies.

Answer 4 (b)

A Smart energy grid and smart electricity distribution is envisioning to meet the requirements of the 21st century in a sophisticated distributing ways with real time transmission approaches. For real time transmission the various wired and wireless communication and technological approaches have been integrated with smart grid and smart electrical power distribution system. These wireless communication and advance control system connect consumers to their smart grid station and smart electrical power distribution system by remotely. This research systematically reviews the roll of wireless technologies and network attributes in advancement of smart electrical power systems. In addition, various wireless technologies involved in smart electrical power distribution such as internet (wide area network), ZigBee, Bluetooth, WI-FI (Home area network) and GSM, WIMAX (Neighboring area networks) has been discussed in this paper. This research particularly focused on the comparison of the attributes, issues and robustness of wireless home area network technologies.

Wireless communication plays a key role in the revolution of the electrical power system. For examples upgrading efforts associated to increased communications in the electrical power system to expand reliability and productivity [1]. It is not only limited to increase the electrical power system productivity but also perform the processes control and monitoring networks throughout the electric power structure. Sensors are mounted to monitor the generation, distribution systems and power used in the system. Furthermore, these operational sensing and control networks can be further classified according to their location. Electricity thieving is common Patrice rest of the countries and Pakistan is one of them. The government of Pakistan losses Rs 86 billion per year due to electricity thieving, unpaid electricity bills, poor infrastructure, line losses, mess management, overstaffing, inappropriate and costly investments, poor quality of services, undue political interference, mis-handling routine matters and law and order situation. To minimize the electricity losses recently the government of Pakistan decided to install the smart meter based on wireless technology. The aim of installation of wireless smart meter will be cut down of theft of electricity at various level [2]. A more interesting byproduct is going to be the ability to top-up your electricity bill. Many researchers and leading companies provide ICT (information and communication technology) solutions in electric power industry into the advance metering infrastructure. The AMI helps electrical power companies to reduce line losses, improve the electricity monitoring, power quality and operating efficiency while reducing consumption, carbon emission and operating cost. The Huawei Company provide smart meter infrastructure for the improvement of billing systems, line losses analysis and device based consumer interaction. Generally, the more advancement in electrical power supply and demand system needed to make the grid stations more reliable, secure and efficient. This can be possible to make by future electrical power network smarter by embedding the real time communication modules with power grid and distribution sites. To address the encounters of the present electrical power grid system an advance concept of smart electrical grid has emerged. The smart electrical power grid system and smart distribution system can be considered an advance electrical power grid structure for improving effectiveness and reliability over automatic control system, advance transmission and distribution network, electricity sensing devices, new energy management methods, smart meter technologies, and high electrical power converters make faster the transmission and distribution of powers. The government of Pakistan started to install the electrical energy mobile meter reading processes through the mobile phone based on android application. The main purpose of these android based mobile meter reading is to improve the efficiency, accuracy and transparency with in system performance and system response. According to the direction of National Assembly of Pakistan these procedures have been originated by electricity distribution companies in Pakistan. After the deployments of these system a significant decrease has been noted in the number of grievances. MMR (Mobile meter reading) schemes has been in progress in several areas of rural areas of Pakistan.

4.1 WIRELESS TECHNOLOGIES USED IN SEGDS

Additional efforts have been initiated to make more efficient the smart electrical power grid and distribution system. This is known as SEGDS or smart grid, intelligent grid and advance grid system. The SEGDS is responsible for fast delivery of electricity, provide security, and protect consumer privacy, monitoring real time energy consumption, transmission and smart distribution by using the various wireless technologies according to the preferences of electricity consumers. The wireless technologies make smarter and intelligent the grid and distribution system of electricity. Figure 3 represent the various wireless technologies used by smart energy grid and distribution system in electrical power structure. Various wireless communication mediums have been identifying to considering in smart grid communication architecture, how much capabilities offered by these proposed technologies in terms of bandwidth, data rates, traffic congestion and coverage area. Although, every wireless technology has its own issues, limitation and technological benefits. The potential concerns encounter by various wireless technologies have been highlighted in this research. The frame work in figure 3 shows that several domestic consumers have different preference of electricity utilization in their homes for optimal and smart energy management. Some consumers used Bluetooth technology to transmit the real time energy consumption and a number of other consumers has wireless local area network connectivity for wireless data transmission. Furthermore, some consumers prefer the ZigBee and 2G/3G/4G cellular communication. Besides the advantages and features of wireless technologies it is difficult to categorize appropriate network technologies for smart grid and distributed wireless communication framework. The research paper highlight some technological issues of Bluetooth, WI-FI and ZigBee technology during the incorporation in smart energy grid and distribution infrastructure.

4.2 SEGDS with wireless technologies

Additional efforts have been initiated to make more efficient the smart electrical power grid and distribution system. This is known as SEGDS or smart grid, intelligent grid and advance grid system. The SEGDS is responsible for fast delivery of electricity, provide security, and protect consumer privacy, monitoring real time energy consumption, transmission and smart distribution by using the various wireless technologies according to the preferences of electricity consumers. The wireless technologies make smarter and intelligent the grid and distribution system of electricity. Figure 3 represent the various wireless technologies used by smart energy grid and distribution system in electrical power structure. Various wireless communication mediums have been identifying to considering in smart grid communication architecture, how much capabilities offered by these proposed technologies in terms of bandwidth, data rates, traffic congestion and coverage area. Although, every wireless technology has its own issues, limitation and technological benefits. The potential concerns encounter by various wireless technologies have been highlighted in this research. The frame work in figure 1 shows that several domestic consumers have different preference of electricity utilization in their homes for optimal and smart energy management. Some consumers used Bluetooth technology to transmit the real time energy consumption and a number of other consumers has wireless local area network connectivity for wireless data transmission. Furthermore, some consumers prefer the ZigBee and 2G/3G/4G cellular communication. Besides the advantages and features of wireless technologies it is difficult to categorize appropriate network technologies for smart grid and distributed wireless communication framework. The research paper highlight some technological issues of Bluetooth, WI-FI and ZigBee technology during the incorporation in smart energy grid and distribution infrastructure.

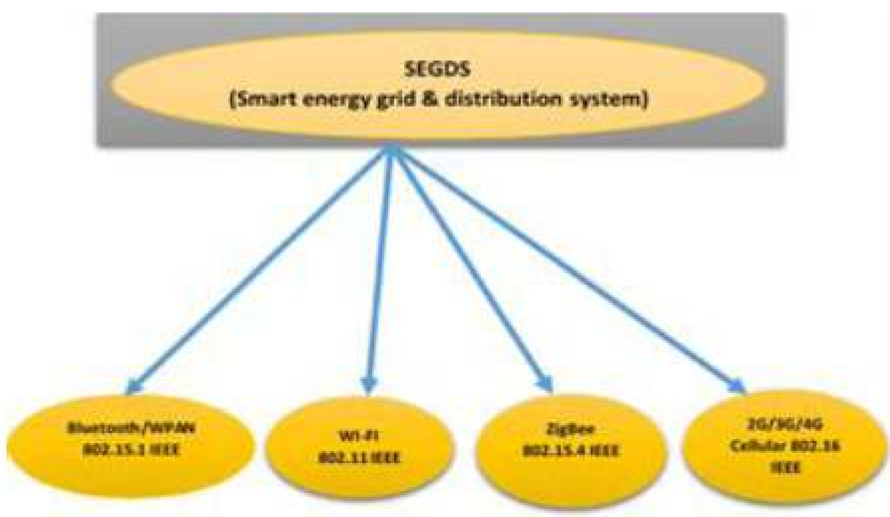

Figure 1. SEGDS with wireless technologies

4.3 Wi-Fi (Wireless Local Area Network IEEE 802.11)

IEEE define a stander 802.11 for Wi-Fi wireless technology with its maximum 11Mbps data rate. It provides single point to multipoint and point to point robust high speed communication. The IEEE 802.11 allows several users to occupy the same frequency channel at a time with minimal interferences to adjutant subscribers. The wireless LAN covering three non-interoperable technologies like direct sequence spread spectrum, infrared technology and frequency hopping at 1 and 2 megabits per seconds (1 and 2Mbps) on 2.4 GHz frequency channel. The other generation of Wi-Fi technology are as IEEE 802.11b, 802.11a, 802.11g, 802.11n and 802.11i. These are the enhanced version of Wi-Fi technology operate on 2.4GHZ and 5.8 GHz frequency channel. The maximum offered data rates 54Mbps to 600Mbps by enhanced versions like IEEE802.11b, 802.11a and 802.11n respectively. IEEE802.11a and 802.11g support up to 54Mbps but both have different operating frequencies. IEEE802.11a operated on 5.8 GHz frequency channel with orthogonal frequency division multiplexing modulation technique where 802.11g used 2.4 GHz frequency band [11]. The IEEE 802.11n is introduced to support multiple inputs and multiple outputs technology and increased data rate up to 600Mbps. The enhanced versions of Wi-Fi (802.11i) support the WPA-2 protocol for cyber security. It has many advantages such as easy to installed, support mobility and less expansive devices.

4.4 Bluetooth

It is a universal short range wireless technology standard for point to point connectivity of a wide range of electronic equipment's. The newly adopted Bluetooth small energy technology is design for low level power sensor equipment's and innovative web application facilities opens the new approaches for companies of domestic meters. This technology is used for monitoring the small devices that are operated on button cell batteries. Bluetooth technology is used in metering system to identify the maximum electricity consumption by the home based electronic devices and it also allow consumers to remotely track, adjustment and control and monitor the utility bill.

4.5 ZigBee

ZigBee is also included in wireless mesh network technologies; it is developed on IEEE 802.15.4 standard. It is sufficient and cost-effective and commercially available wireless technology. However, it supports low data rate on personal area network. This technology is used for reliable message communication, home equipment automation, devices control, monitor health care activities remotely and automatic control of consumer devices [16]. ZigBee uses two band frequency channel for communication such as 2.4 GHz and 915 MHz used direct spread spectrum communication technology for data transmission and reception. The estimated data rate offer by ZigBee technology is 20Kbps to 250Kbps. ZigBee wireless technology is consisting with different functional equipment used for wireless communication. Such as FFD (full functional device), Router and ZigBee end device RFD (reduction function devices).

4.6 Comparison Table of Wi-Fi, Bluetooth and ZigBee

The table 1 shows the related issues in wireless technologies used by smart energy grid station and smart power distribution system. Different wireless technologies have different data rate, coverage area, frequency band, modulation techniques and issues regarding the usage

Wireless Technology	Frequency Band	Data Rate	Coverage	Modulation Techniques	Issues
Wi-Fi	2.4GHZ, 5.8 GHz	1Mbps, 2Mbps, 11Mbps, 600Mbps	32meter or 105fts	DSSS,OFDM	• Interfiace Issues with Bluetooth. • interoperability problem with Bluetooth • Bluetooth and Wi-Fi cannot be operate at same environment • 802.11b has automatic data rate modification • security problems • bandwidth • coverage • traffic injection and modification [18] • 2.4Ghz frequency band • Quality of service
Bluetooth	2.4Ghz	2.1Mbps	10meter or 33fts	FHSS	• Data throughput degradation problem in existence of WI-FI • do not support same environment • lack of automatic repeat request when sensitive data is lost • lack of security • bandwidth • coverage • frequency agility • used same frequency band 2.4Ghz
ZigBee	2.4Ghz, 5.8Mhz	20Kbps, 250Kbps	10-20 meters	DSSS	• Heat up issue • data rate • coverage • channel overlapping with other wireless technology • use same frequency band 2.4Ghz[19] • latency • Quality of service[20]

Table 1. Issues, coverage, frequency and bandwidth comparison between various wireless technologies

Answer 4 (C)

SMART METER ISSUES AND CHALLENGES

In general, replacing the traditional meter with a smart meter can be done with more advantages. However, the design, deployment and maintenance of the smart meter lead to different issues and challenges. Furthermore, the implementation of a smart meter in a distributed system requires spending a tremendous amount of money to invest as well as the network and related software tools. Consequently, replacing the conventional meters with a smart meter may be a challenging for utility companies and customers. Though several devices are integrated with smart meter system, the full benefit of these devices extent only when all the appliances and devices in the distribution and metering network are included in the communication network. Integrating of these devices becomes more complicated as a huge number of customers start using the smart meter. Additionally, smart meters create potential privacy and security issues as the data and signals are transmitted via a network. Furthermore, the data might also have different information about the customer (e.g. sensitive information). In addition, having information about the appliances such as what appliances are in use, appliances IDs, etc. via a network might pose security threats. In order to communicate the data and control signals with the central unit, smart meters have to run these commands of controlling devices from the utility companies. Smart meters operations involve a huge quantity of data to be transferred between smart meters and the server as well as the consumer's system. Thus, securing these data and choosing the right network can be a difficult job. Moreover, several smart meter communication networks use a low bandwidth, which leads to generating a high traffic and limits in the quantity of data to be transmitted. These problems make the data unsecure. Integrating of these devices will lead to a huge quantity of data transmitted the need to have a memory to store these data. These requirements could lead to increase the overall deployment costs. There are different issues related to the security vulnerabilities and these issues might be related to (weak authentication, quality the software, weak protocol, weak network, weak error handling, etc.). In spite of these issues, some utility companies pay less attention to the maintenance of their communication networks and these can lead to safety issues. Even if these companies use wired communication, in this case, a physical damage to the cable might also cause an interruption in data transfer.

In general view, efficient management of the grid can be an alternative solution instead of revamping the existing grid. But, in view of technical advantages and enhancements to operation capability, integration of the smart grid stands as a valuable solution in managing the existing grid. However, the design, deployment and maintenance of the smart meter system involve many issues and challenges. Implementation of smart meter system in the distribution system involves several billion dollars of investment for deployment and maintenance of the network. Indeed, justifying the investment is difficult. So, this investment has to be realized as a function proportional to the projected increase in the energy demand and portion of the distributed generation. Initially, the process of replacing the existing energy meters with a smart meter system will be a challenge for utility companies. Lack of proper infrastructure for synchronizing this new technology with the existing ones might interrupt the introduction of smart meters. Though several devices are integrated with the smart meter system, they can be used to their fullest extent only when all the appliances and devices in the distribution and metering network are included in the communication network. Integration of the devices becomes even more complicated with an increasing number of customers. Deployment of communication network in some localities might be difficult due to terrestrial difficulties. In the USA, utility companies receive incentives for selling more electricity, which might not drive them to encourage their customers to conserve energy. Collection and transmission of energy consumption data is a continuous process that is done automatically, but it is a tedious and expense job. In this context, a common notion might arise in several customers is that, smart meters they might essentially create some privacy and security risks as the data and signals are being transmitted. Additionally, this data might also reveal the information about presence of people at their residence, when they were present, and what appliances are in use. In view of this, some customers might be unwilling to communicate their energy consumption data with their neighbor's meter. Fundamentally, it would be an issue about the choice of parameters to be transmitted and administrator authentication to access that information. In addition to communicating the data and control signals with the base station, smart meters must execute these control commands from the utility companies. Operation of a smart meter system involves a huge quantity of data transfer between a smart meter and the server located at the base station. Maintenance, management and storage of data could be a tedious job. There are many technical issues that might be considered during selection of communication network. In addition, most of the smart meter communication networks use low bandwidth, which generates high traffic and limits the quantity of data to be transmitted. Integration of devices for modulation, demodulation and additional memory for storing the data logs could increase the overall deployment costs. Energy consumption data transmitted through public communication networks like cellular networks might involve security risk. Other possible security vulnerabilities might be weak authentication, quality of implemented software, error handling, weak protocols, and improper session management. In spite these issues, though deployment and maintenance of some communication networks are cheap, utility companies might encounter some challenges in the form of limitations in network coverage, data capacity, and propagation issues. In addition, data concentrators may lead to accommodation and safety issues. In case of wired communication, physical damage to the cable might also cause discontinuity in data transfer.

Figs.1,2,3 illustrate various issues and challenges in design, deployment, utilization and maintenance of the smart meter system. Apart from utility companies, there are certain sections of people who might be interested in collecting and analyzing the energy consumption data of a customer. They include revengeful ex-spouses, civil litigants, illegal consumers of energy, extortionists, terrorists, political leaders with vested interests, thieves, etc. for knowledge about people's presence at their homes. Quantification of the potential benefits from smart metering is very difficult due to the lack of historical data. Future of smart metering depends on the policies of utility companies and respective governments. Though customer gateways are intelligent and are easily compatible with other devices, they are prone to physical as well as cyber security risks. In addition, energy meters are located in open and insecure environments and need proper shelter to be physically secure.

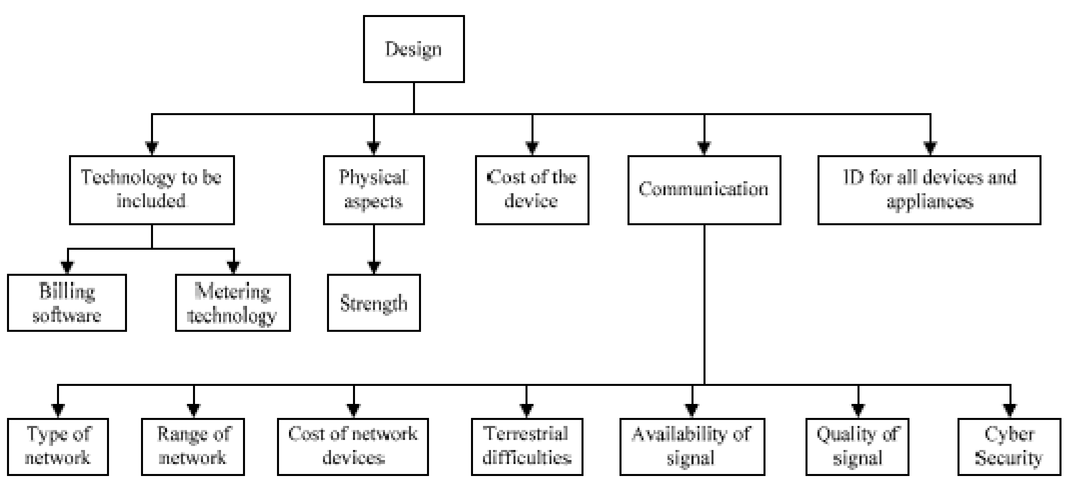

Fig1 Design issues for a smart meter system.

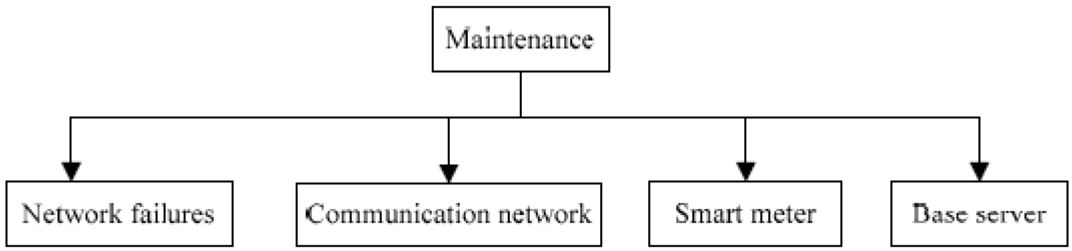

Fig. 2 Maintenance issues for a smart meter system.

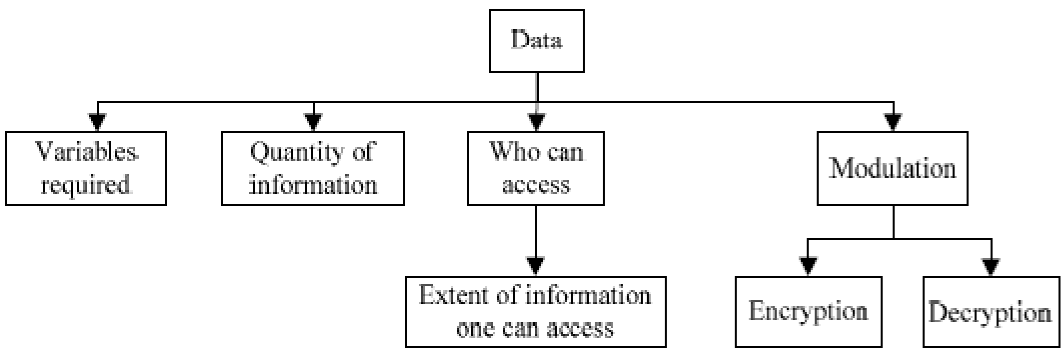

Fig. 3 Challenges with data transfer for a smart meter system.

Fig. 1, illustrates several major design issues and constrains including the extent of technology to be included; this technology might include the kind of billing, control systems related software and other metering technology, the physical safety aspects such as positioning of the smart meter and physical strength of the structure that houses the smart meter components, cost of the smart meter devices, specific ID to identify all smart meters and other components in the smart meter network, and the type of communication infrastructure required, including overall cost for the data collectors, data repeaters, transmission, antenna system, type of network to be chosen based on terrestrial difficulties, availability of signal, cyber security, type of the signal and range of the signal. After deploying the required infrastructure, next major encounter would be the maintaining all the components of the network in case of any failure. Maintenance of network include issues with the base server that stores the energy consumption data, software and hardware issues with the smart meter, electric network as well as distribution network failures. Besides these issues, dealing with the data could be another major issue. They include quantity of data to be transmitted, what are the variables to be transmitted, the extent and quantity of information that the customer and the utility companies, can access parameters, parameters required to represent the energy consumption, modulation of the data before transmission, demodulation of the data at the reception.

Answer 4 (d)

Electrical power systems across the globe are undergoing transformations owing to the challenges they face in matters of production, reliability and efficiency. Fast deterioration of conventional power resources makes urgent call for replacement with alternative renewable sources. Existing power grids with vertically integrated structure shall not support this on a commercial basis. Apart from hydro and perhaps wind power, non-conventional energy resources are not available in abundance hence making them unfit for mass production. Moreover, the highly scattered nature of their availability and lack of reliability definitely eliminate the possibility of a centralized production but with decentralization of the existing network and along with the introduction of distributed generation certainly throws light to a feasible solution. Numerous power networks across the world have already taken initiatives in this direction. Small-scale generations within the consumer premises, industrial or domestic, are receiving encouragement from utility grid even in the form of economic incentives. Once installed, distributed generators have proven beneficial to both the suppliers and consumers along with the strengthening of grid reliability. With the aim of enhancing the efficiency of such a decentralized network, conventional power systems have been experiencing transition from centralized supply side management to decentralized supply and demand side management. Therefore, load management under the new operating environment becomes more difficult than that under the conventional environment. Currently, the electrical energy consumption is not efficient in most buildings mainly because of consumers' ignorance. Grid overloading especially during peak hours has become common which may even ultimately result in grid failure. Besides, this also results in the wastage of a large amount of resources. An attention from the load end by adopting techniques such as Demand Response (DR) could bring about definite improvement in this aspect. The wastage of energy can also be controlled in a more efficient manner if the utilization is being managed from the consumer side rather than from the supply side. The total effect of this demand response will be huge and will have a greater impact on reduction of the supply-demand gap.

4.1 NEEDS AND BENEFITS FOR LOAD SCHEDULING

A hike in the purchase of electrical appliances following a rising standard of living causes a growing demand for energy in domestic buildings. Inefficient use of these appliances causes wastage of energy. One way to tackle this is to give feedback to the consumers on their behavior, which may lead to a reduction in this wastage. Another way to reduce energy consumption is the application of demand side load management. The first method, even though makes the users realize their unhealthy trend of energy utilization, will not suggest any proper method for them to follow so that they could rectify the issue. Therefore, the best way to ensure the solution is to adopt the technique of DR. The implementation of DR could be carried out through different methods among which valley filling and peak load shaving is the ones, which directly affect the peak demand reduction. In order to accomplish this load shaping, the loads have to be scheduled properly by the user so that heavily rated loads are not turned on unnecessarily during peak hours. The concept of demand side load management is gaining importance. Various methods are available to implement it such as peak clipping, load shaving, valley filling etc. that tries to relieve the grid from peak hour overloads. Dynamic pricing is another way to have a control on load commitment that offers economic benefit to the consumers if they utilize the utility efficiently.

This method encourages users to shut down heavy loads during peak hours and utilize grid during off-peak hours by charging distinctly and dynamically. Load management after identifying the schedulable loads like thermostatically controlled household loads was presented by P.Du and N.Lu .Game theory and optimization algorithms are employed to have appliance commitment in buildings. Scheduling loads based on priority and optimization algorithms has also received much attention. It incorporates dynamic pricing technique, typically the Time of Use method and brings about DR.

4.2 OFF-LINE LOAD SCHEDULING

Load scheduling at the consumer end for energy management is a feasible option once it is designed and executed with appropriate care suitable for the load environment. The present work tries to manage loads in a building that is supported by Hybrid Renewable Energy Systems (HRES) consisting of solar panels, wind turbines and battery along with an uninterrupted grid connection. The renewable power generators were designed to have an installed capacity of 20% of the total connected load in the building. A set of 4 solar photovoltaic (PV) modules each of power rating 150 Wp, 5 wind turbines each of 500 W rated power output and a battery bank consisting of 4 units of 100 Ah each were considered. The modelling of these components of the HRES was done. With the model in hand, hourly renewable energy availability was estimated considering forecasted solar irradiation and wind velocity data for a day under the assumption that these values would remain constant for a particular hour. With this renewable energy forecast available in prior, the off-line scheduling algorithm was developed that was built in steps starting with categorization of the loads, load prioritization and then incorporation of tariff plans at a later stage.

A. Load Categorization

Home appliances are initially classified into three categories, namely, appliances with real-time energy consumption mode, appliances with periodic non real-time energy consumption mode, and appliances with no periodic non real-time energy consumption mode. The energy consumption of the first category of appliances is directly related to consumer behavior, which means that after the consumer turns them ON, the appliance must be energized until they are shut down. The energy consumption of this type of appliances cannot be scheduled and they must run immediately to satisfy the consumer's requirements. Lights, fans, desktop PCs and television are examples. The energy consumption of the second category of appliances is periodical and fluctuant when they are in use. Air conditioners and refrigerators are examples. They could be scheduled based on maintaining the set value of temperature i.e., they need to be energized only when the temperature violates the upper or lower limits. Battery embedded devices such as laptops shall also be considered under this category. The third type of appliances consumes energy non-periodically and does not have any specific time to run. However, they must serve their course before certain deadline. Plug-in Hybrid Electric Vehicles and pool pumps come under this category. The first category devices could be energized purely based on consumer behavior whereas the other two categories are schedulable loads.

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B. Load Prioritization

The appliance commitment can be based upon the necessity of energy consumption by that appliance at any point of time. Again, the need or urgency of an appliance over the others should be considered for an even and efficient scheduling. This can be ensured by allocating priority to the devices dynamically considering their status.