A report on

POWER SYSTEM ANALYSIS IN SMART CITIES

submitted in the partial fulfilment of the requirement for the award of degree of

BACHELOR OF TECHNOLOGY
(Electrical Engineering)

by

Nilabh Jha (2K18/EE/127)

Pranshu Kukreti (2K18/EE/141)

under supervision of

Professor Vinod Kumar Yadav

DEPARTMENT OF ELECTRICAL ENGINEERING

DELHI TECHNOLOGICAL UNIVERSITY

(2020-21)

Certificate

This is to certify that Nilabh Jha and Pranshu Kukreti, B. Tech. students in the Department of Electrical Engineering have submitted a project report on "POWER SYSTEM ANALYSIS IN SMART CITIES " in partial fulfillment of the requirement for award of degree of Bachelor/Master of Technology in Electrical Engineering, during the academic year 2020-21.

It is a record of the students' research work prepared under my supervision and guidance.

Mr Vinod Kumar Yadav

Professor

Department of Electrical Engineering, Delhi Technological University

Abstract

A smart city is a sustainable and efficient urban centre that provides a high quality of life to its inhabitants through optimal management of its resources. Energy management is one of the most demanding issues within such urban centres owing to the complexity of the energy systems and their vital role. For highly populated Asian countries like India , the smart cities may play numerous positive roles resulting in efficient utilization of available infrastructure. This can be achieved by transforming existing infrastructures into smart ones. To start with such transformation, the main emphasis would be given to energy. For this purpose, the model of a framework capable of analyzing emerging trends in upcoming power system to make it more reliable. This research work focused on the significance of implementing advanced systems like smart grids. Therefore, significant attention and effort need to be dedicated to this problem. The Smart City concept includes Smart Energy consideration with preferable usage of renewable energy sources, especially Smart Grid and solar roof-top PV power plants. A smart grid is an evolved grid system that manages electricity demand in a sustainable, reliable and economic manner, built on advanced infrastructure and tuned to facilitate the integration of all involved. In the world of the Smart Grid, consumers and utility companies alike have tools to manage, monitor and respond to energy issues. The *Electric vehicles may be considered as energy storage units, thus enabling in-grid PV plant structure. The paper introduces the basics about smart city and analysis of smart energy using electrical energy, smart grid and discuss clean energy supply as a part of Smart Energy concept for the new, upcoming electric transportation sector in the Smart City environment.*

Content

Introduction

The recent demographic summary of India shows that annual rate of urbanization is 3.3%. Currently 32% percent of Indian Population resides in urban region . This ever-increasing population rate in urban areas led to development of smart infrastructure and there is a need to device proper framework which may address improvement in the overall infrastructure of big cities to make them smart cities. Although many articles have been published about smart cities, there is no one agreed definition of what a smart city is. Each interpretation varies on how a city achieves this 'smart' status. There is no defining technology, service, or system necessary to grant a city the 'smart' label.
A smart city is "an urban area that uses different types of electronic Internet of things (IoT) sensors to collect data and then use this data to manage assets and resources efficiently." Key words here are **sensors** and **data**. Smart cities use both to provide insights and interventions to address common urban challenges.
The concept of smart cities involves specifically modified infrastructure for its physical, economic, and social systems which is mandatory to provide improved facilities to citizens at various levels. The major infrastructure is energy which is mainly distributed in the form of Electricity. Therefore, power system operation must be optimized by making it intelligent and environmentally friendly by including renewable resources and green ICT systems to achieve greater energy efficiency.

Value is given to the smart city based on what they choose to do with the technology, not just how much technology they may have.
Several major characteristics are used to determine a city's smartness. These characteristics include:

- A technology-based infrastructure
- Environmental initiatives
- A high functioning public transportation system
- A confident sense of urban planning and
- Humans to live and work within the city and utilize its resources.

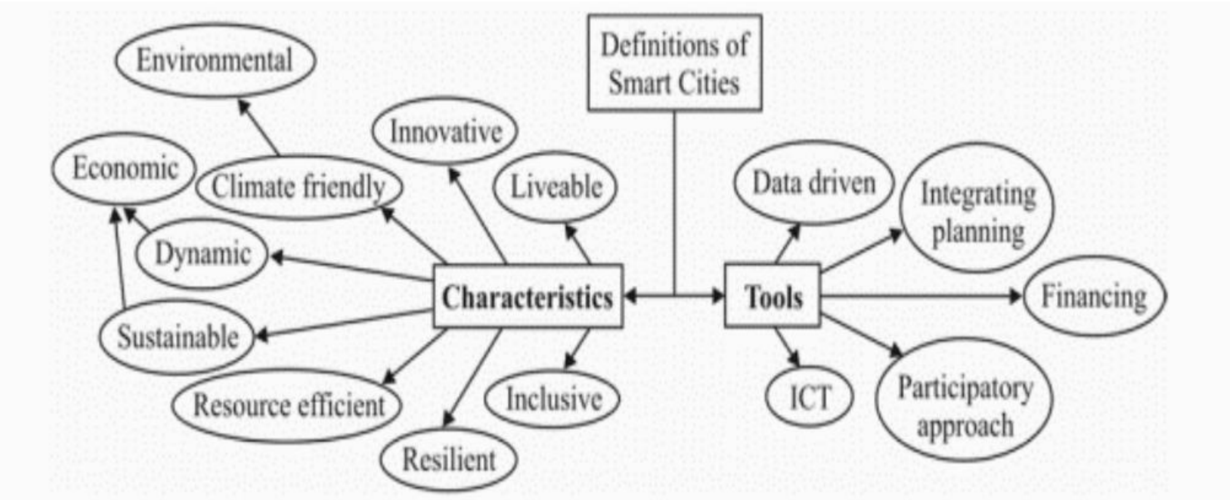
A smart city's success depends on its ability to form a strong relationship between the government -- including its bureaucracy and regulations -- and the private sector. This relationship is necessary because most of the work that is done to create and maintain a digital, data-driven environment occurs outside of the government. Surveillance equipment for busy streets could include sensors from one company, cameras from another and a server from yet another.

DEFINITION OF SMART CITIES IN EU POLICY

Cities around the world occupy only 2% of Earth's surface yet emit almost 80% of global carbon dioxide as well as significant amounts of other greenhouse gases. Energy use is responsible for approximately 75% of these emissions. Pillars of the EU's overall policy are built upon the current context of climate change issues, increasing energy costs. EU has taken an initiative by launching a concrete policy framework to make their cities capable of more energy efficient, reduction of relying on fossil fuels achieving reduction Carbon Dioxide emissions, improved impact by adding renewable energy resources to power grid. The implementation of this significant policy framework would also result in climate improvement. The EU is targeting year 2020 to accomplish such implementations. In India, the similar approach may be adopted to deploy environmental friendly infrastructure for power system operation including both electricity 2 generation scheme and distribution. Electricity generation and distribution is considered as key infrastructure because increasing load demand may result in contingent scenario and power system operation may become more prone to failure. This crucial electricity infrastructure inclines towards deployment of Information and Communication Technologies (ICT). This ICT infrastructure may supervise inclusion of renewable resources using powerful monitoring and controlling features thus transforming the conventional power grid into an intelligent or smart grid.

Characteristics of the smart cities

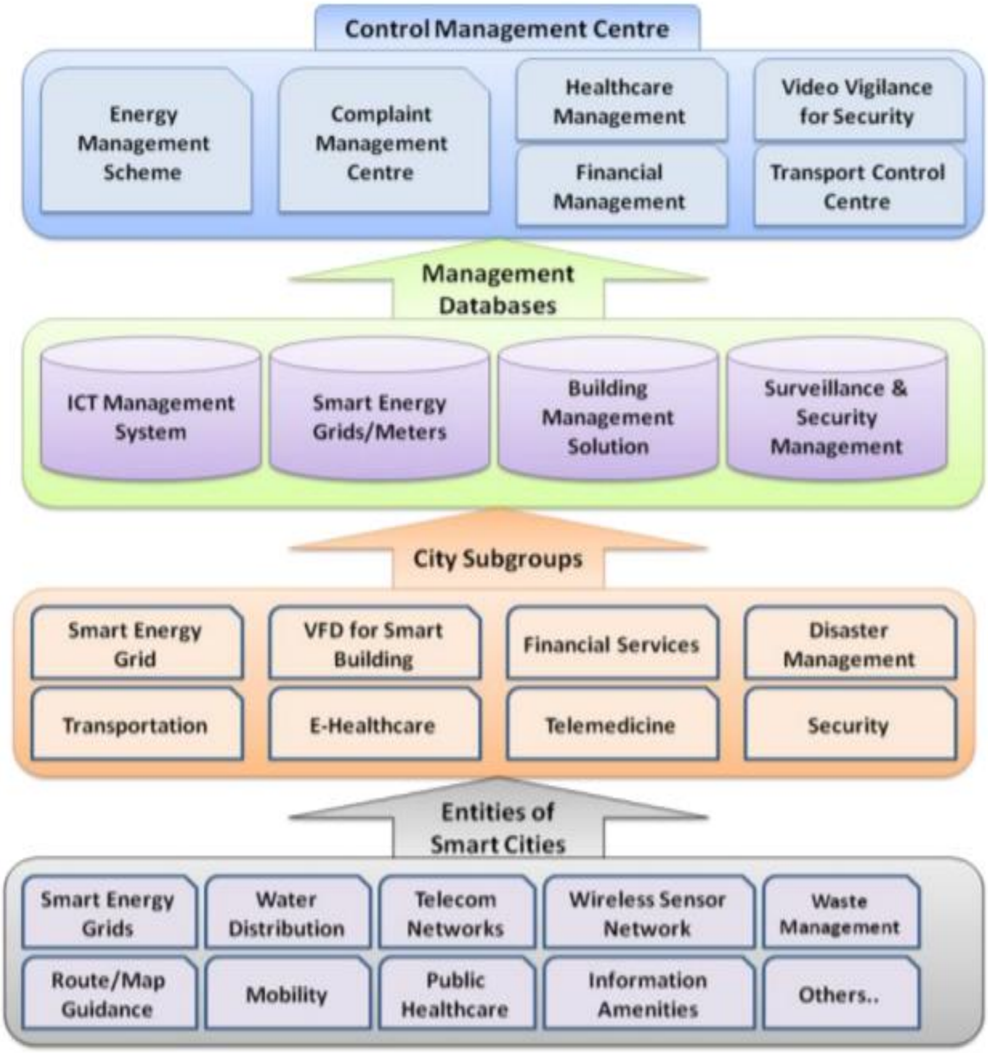
The intelligence of a city is given by the set of physical and legislation infrastructures that support the economic development, ensure social inclusion, and allow environment protection. Figure below illustrates the main characteristics of a city and its tools, available for both the municipality and citizens, that can transform a city into a smart one.



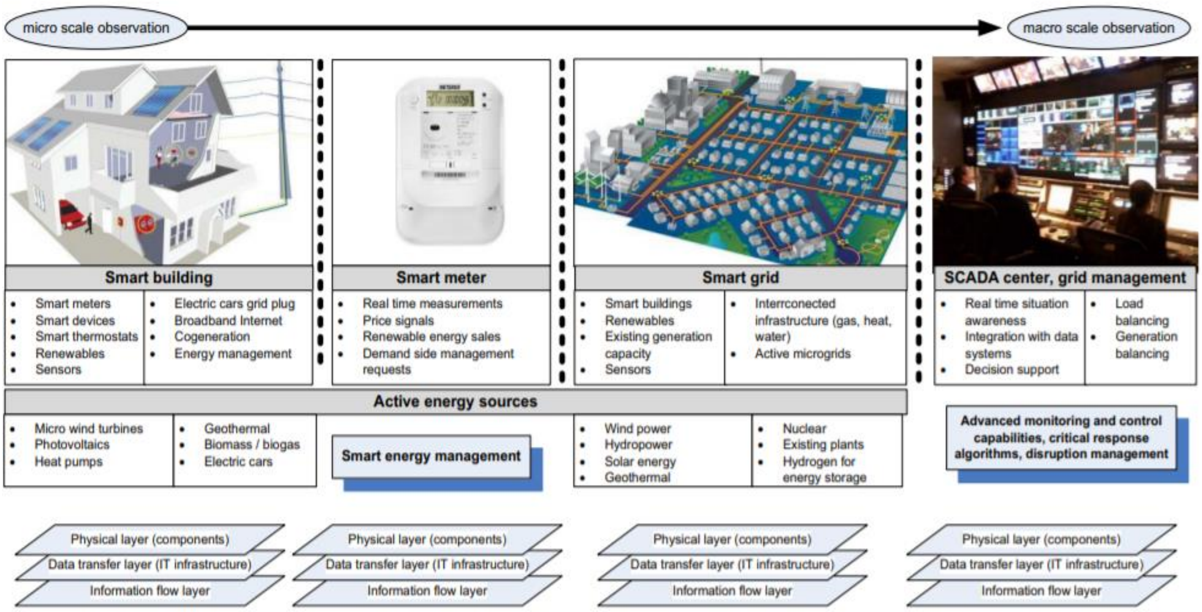
The International Organization For Standardization in the domain of Sustainable development of communities, defines 17 key indicators for evaluation of performances of cities from the point of view of ensuring urban services and quality of life, that is economy, education, energy, environment, finance, fire and emergency response, governance, health recreation safety, shelter, solid waste, telecommunications and innovation, transportation, urban planning, wastewater, water and sanitation. These indicators, that can include several sub-indicators are reference for city managers, politicians, researchers, business leaders, planners, designers and other professionals to focus on key issues, and put in place policies for more lovable, tolerant, sustainable, resilient, economically attractive and prosperous cities.

Infrastructure of Smart City

The infrastructure of any smart city shall focus on some significant entities that are generally flexible to include more units as per requirement. Figure below represents such entities along with various subgroups for optimal planning. These subgroups can be managed by implementing various management systems e.g., ICT Management System. Finally, a control management center may provide centralized monitoring and controlling these entities such as smart energy grids and variety of Telecommunication Networks.



Smart city electricity infrastructure



Smart buildings

In the 1980s "smart" was a building with implemented passive energy efficiency measures. In 1990s it was buildings with central, computer operated infrastructure systems.
The definition of the term smart building today includes all previous meanings with the addition of networked appliances, advanced energy management and renewable energy sources,
Smart buildings communicate with its surroundings (i.e. the energy distribution networks), and can adapt to conditions in the network, which they can monitor and receive signals from. They communicate between themselves, exchanging both information and energy, thus creating active microgrids which, except consumption, can include small renewable and non-renewable energy sources.
In general, the smart building consists of:

- Sensors - monitoring of selected parameters and submit data to actuators.
- Actuators - which perform physical actions (i.e., open, or close window shutters, turn on appliance, etc.)
- Controllers – monitoring inputs from sensors, managing units and devices based on programmed rules set by user
- Central unit – used for programming of units in the system.
- Interface - the human-machine interface to the building automation system
- Network - communication between the units (RF, Bluetooth, wire)
- Smart meters - two-way, near or real-time communication between customer and utility company

<u>Features:</u>

- Today's buildings incorporate principles of energy efficiency.
- Installation of renewable sources on buildings creates further complexities as the building becomes an active generation component of the grid.
- Multiplication of this kind of buildings creates local networks capable of acting as distributed generation but also as self-sufficient energy communities, without the need for external remote supply of electricity.

Smart Meters

Traditional meters provide one-way information and are either read in person by a meter reader or remotely, up to a frequency of one readout per month, if applicable. **Smart meters** are digital meters that offer two-way communication allowing for more interactivity between the consumer – the smart building and the utility. The concept is already expanding to water, gas and heat networks.

Characteristics of a smart meter are:

- Real-time measurement of energy consumption and electricity generated locally.
- Two-way communication with the utility whereas the utility can read data from meters remotely and can send information to the meter.

Advantages:

- Ability to enable bidirectional communication between smart electricity meters and utilities across a wide area, whether with high or low population density
- Upfront costs of deployment are possibly lowered since the utility does not need to build private communication infrastructure.

Limitations:

- being subject to the coverage provided by the public networks,
- changing protocols,
- operational costs

Smart meters enable full information awareness to the utility as well as enabling active consumers to become participants in the grid load. In turn, these meters can receive real-time data on grid conditions, load, and pricing from the market.

Smart meters are a steppingstone to smart grids, a dynamic ‘energy Internet’ or ‘information utility’. Following the transformation process of the telecom industry with the introduction of mobile telephony, smart meters are expected to trigger new energy market models as features of smart grids reach implementation stage.

Smart Grid

A Smart Grid is an electricity network that can intelligently integrate the actions of all users connected to it - generators, consumers and those that do both—in order to efficiently deliver sustainable, economic and secure electricity supplies.

A Smart Grid employs innovative products and services together with intelligent monitoring, control, communication, and self-healing technologies to:

- better facilitate the connection and operation of generators of all sizes and technologies
- allow consumers to play a part in optimizing the operation of the system.
- provide consumers with greater information and choice of supply.
- significantly reduce the environmental impact of the whole electricity supply system.
- deliver enhanced levels of reliability and security of supply.
-

Aims of the Smart Grids—The Vision

- Provide a user-centric approach and allow new services to enter into the market.
- Establish innovation as an economical driver for the electricity networks renewal.
- Maintain security of supply, ensure integration and interoperability.
- Provide accessibility to a liberalized market and foster competition.
- Enable distributed generation and utilization of renewable energy sources.
- Ensure best use of central generation.

- Consider appropriately the impact of environmental limitations.
- Enable demand side participation (DSR, DSM)
- Inform the political and regulatory aspects.
- Consider the societal aspects.

Development of smart grids in cities relies on five basic directions:

- Promoting clean energy source.
  The smart cities are evaluated from the point of view of using clean energy A The smart grid solution are key factors for supporting the development of renewable energy sources (RES) and high-efficiency cogeneration power plants. Integration of distributed sources in a safe and reliable manner provides flexibility in supplying electrical energy to the consumers.
- Smart metering,
  Developing the Advanced Metering Infrastructure (AMI), one of the key factors for smart city strategy, will allow, through remote data reading and bi-directional communication, an active participation of the consumers to load balancing in critical situations and implementation of dynamic tariffs in order to stimulate the integration of renewable energy sources and electric vehicle. On the other hand, AMI will allow the operators (distribution operator, energy supplier or the municipality) to elaborate load forecasts for various load intervals.
- Efficient public lighting.
  The municipalities show an increased interest to adopt sustainable solutions as a measure to improve the energy efficiency. Some examples are the use of low consumption and highefficiency lamps for the street lighting (for instance, the LED-based lamps) or the use of sensors to automatically switch on/off the light when necessary, including the lighting in the administrative buildings.
- Integration of the electrical vehicle.
  The air pollution in cities is one of the most important public health problems. Large scale integration of electrical vehicles requires intelligent solutions to be adopted in electrical networks. Management of battery charging is essential to avoid network overloading and to support optimized use of clean energy. The electrical vehicle is a mean for handling the surplus of energy from renewable sources, mainly during the night periods.
- Active involvement of consumers.
  The new smart grid applications are oriented toward the consumer, smart grids are customized to inform, educate, and assist the consumer in taking the best decisions. By integration of electrical vehicle and supporting the small power energy sources, the consumers may become prosumers, having thus the possibility of injecting power into the electrical network during the peak load periods. The consumers can, therefore, be actively involved in the efficient use of energy.

In order to achieve the objectives above presented, a smart grid must be developed on three levels:

- Physical Infrastructure
  Smart grid is a necessary industrial and economic revolution taking into consideration aging that can be still found in substation, electrical lines and transformers. With the advent of computation techniques and the innovations in the electrotechnical materials it is now possible to manufacture electrical equipment and advanced automation, protection and control systems.
  Currently, most of these technologies are already available, which allows doing the first

steps in developing the smart grid:

- The important levels of automation, communication and information technology which are today available can ensure a high-reliability level of the distribution networks in cities,
- It is obvious the trend for equipment modemization both in substations and field installations so that the reaction time is very much reduced in the case of fault isolation, fault location and restoration, network reconfiguration and voltage and reactive power control:
- The increase in the share of renewable energy sources requires the employment of new protection equipment adapted for these situations and special circuit configurations in substations. More than ever, installation of equipment and protection schemes complies with specific standards and the principles of integrating the information data driven applications are becoming essential elements in the modern design.

➢ IT&C Infrastructure

The intelligence of an electrical network is given by the software applications and the communication infrastructure that connects the operators with the network components. Smart grid development is thus possible because of the innovation in the IT&C domain, visible mainly in the last 15 years The large scale implementation of the IT&C infrastructure inherently allows the possibility of remote access to information, including the access to the command and control systems thus existing the risk of unauthorized access Under these conditions, protection against cyber physical attack is critical to prevent economic losses.

➢ Standardization

The novelty of the smart grid and smart city concepts is a barrier for compatibility of the large number of equipment provided by many companies in the field, in their goal of rapidly providing innovative solutions at the same time with sustainable economic development. In order to ensure a harmonized integration of all equipment and to reduce the operation costs, a suitable standardization is required.

Comparison between Traditional Grids and Smart Grids

Table 1: Comparison between Traditional Grids and Smart Grids

	Current Grid	Smart Grid
Communications	None or one-way typically not real-time	Two-way, real-time
Customer Interaction	Limited	Extensive
Metering	Electromechanical	Digital
Operation & Maintenance	Manual equipment checks time-based maintenance	Remote monitoring Predictive condition-based maintenance
Generation	Centralized	Centralized and distributed
Power Flow Control	Limited	Comprehensive
Reliability	Prone to failures and cascading outages	Pro-active real-time protection and islanding
Restoration	Manual	Self-healing
Topology	Radial	Network

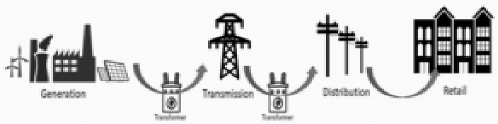


Figure 1. Traditional energy distribution systems.

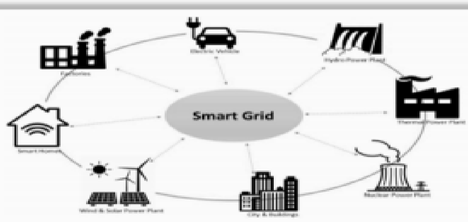


Figure 2. Smart future infrastructures.

Transitional Phase

Renewable energy sources at distribution and transmission network level are already common. The ongoing process is implementation of renewables and other micro sources on buildings, coupled with introduction of smart devices and smart meters, which is a precondition of creation of smart grids. The costs of such initiatives is high, hence new developments are currently implemented in phases, in the form of multiple pilot projects Networking developments along with national smart meter rollout campaigns and incentives for renewables will create full scale smart grids, which are the basic infrastructure of smart cities.
Figure smart city electrical infrastructure shows that at each domain of the smart city electricity infrastructure – smart building, the metering system, smart grid and the grid management system, three basic layers can be observed, as follows:

- Physical components – devices and other physical infrastructure, such as power lines, photovoltaic panels, wind turbines, GSM towers, sensors, etc. that are used to deliver essential services.
- Data transfer layer – consisting of data transfer media, computers and telecommunication networks that are used to gather and transfer data to and from physical components.
- Information flow layer – Next generation supervisory control and data acquisition (SCADA) systems are the main part of this layer, with added functionality of energy management systems (EMS). Data processing and decision making are performed at this level, where a human operator is also involved in the process. Commands are issued via the data transfer layer to physical components in order to optimize operation.

The presented paradigm of the smart city electricity infrastructure with three underlying layers has strict survivability requirements on a twenty-four-hours-a-day, seven-days-a-week (24x7) basis for each layer. Here survivability means the capability of a system to fulfill its mission in a timely manner, even in the presence of failures, attacks, or accidents. In difference to fault tolerant systems (such as the electricity grid) which are generally engineered to tolerate random natural failures, system survivability must also consider unpredictable faults which may be caused by emergent phenomena such as terrorism, natural hazards, large disruptions, market disturbances, international policy shifts, etc.

Power System Operation in Smart Cities

The smart grid mainly enhanced by establishing digital communication between the electricity provider and smart meters installed at residences. Such a system is commonly known as an advanced metering infrastructure (AMI) or an Automatic Reading System (AMR) . A smart meter is capable of constantly monitoring consumption of electricity at a residence or building for the electric utility company. In the other direction, the smart meter is capable of providing active time of utilization i.e., pricing information to the consumer such as different tariff plans according 3 to peak or off-peak demands. It will optimize the transmission and electricity cost. This set of information can be used to switch off certain devices (using intelligent circuit breakers) to prevent complete shut down for an area during peak demand. This deployment of two-way digital communication network may revolutionize the conventional correlation between consumers and electric utility companies into a more effective way for communal benefits. At one end, the consumers may get benefit by taking intelligent steps about their energy usage and operating cost. The electricity providers may manage sustainability of the system if load demand increases on the other end. There are several ways to ensure sustainability but the addition of renewable energy resources with existing grid capacity in an intelligent manner can be an effective solution. In this intelligent way, an optimized transmission policy may be developed as described in figure 2 by incorporating optimal power flow, contingency analysis, and determination of good locations. Such generation policy can be implemented using a High Scale SCADA System.A set of proactive measures executed automatically by means of well-defined control algorithm or manually by assistance of an operator to mitigate the unwanted effects of a contingency event or it may strengthen the system to withstand a probable future contingency.

The Contingency Analysis has been implemented to achieve the following goals:
(a) Determine performance characteristics for generation, transmission, and renewable technology
(b) Identify locations within system where sufficient renewable generation can effectively address transmission problems

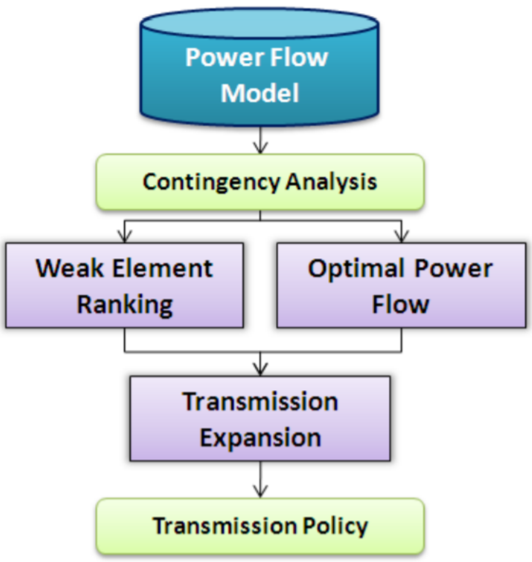


Fig. 2 Flow diagram to describe optimal transmission policy

The smart cities surely get benefit from communications technologies and sensor capabilities added to infrastructures for optimized power system operation. The Smart Residences or Buildings are capable of exchanging information thus resulting in smart grid operations. The major entities of power system operation in a smart city are shown in figure 3. The attributes of a smart home give access to variety of options for optimal demand management for the utility provider and better pricing management for the consumers. For example, Variable Frequency Drives (VFDs) are essential part of building automation resulting in smart Heating Ventilation and Air Conditioning (HVAC). Therefore, energy efficiency can be obtained in current smart buildings and smart homes.

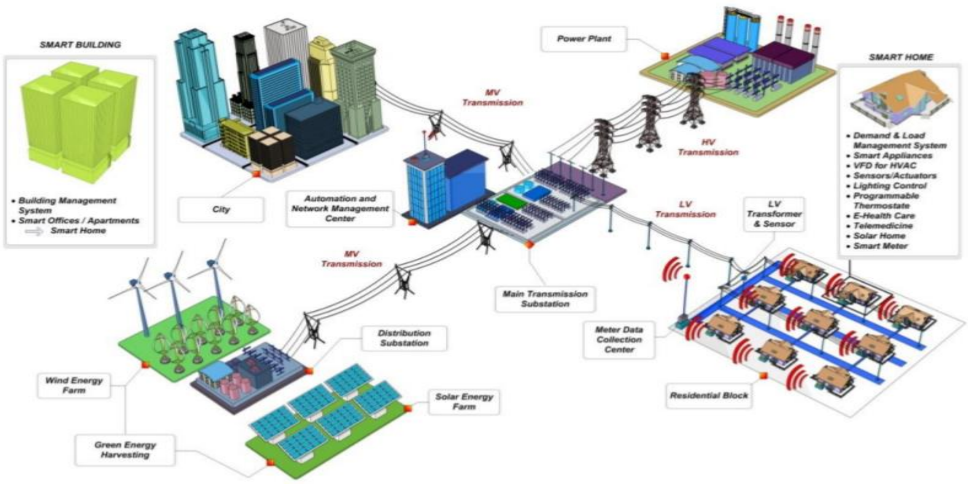


Fig. 3 Major entities of Power System Operation in a Smart City

Mathematical Model for Congestion Management

The power flow P_{jk} is through the transmission line j – k is a function of voltage magnitudes V_j and V_k the line reactance X_{jk}. This power flow is also dependent upon the phase angle between the sending and receiving end voltages denoted by δ_j, δ_k as described in equation 1

$$\boldsymbol{P_{jk} = \frac{V_j\, V_k}{X_{jk}} \sin\left(\delta_j - \delta_k\right)}$$

It is evident from numerator of equation (1) that power flow can be affected by either varying voltage magnitudes or the power angle. It can also be affected by changing reactance of the transmission line. The reactance of the line can be reduced through series compensation while voltage magnitudes can be varied with support of VAR. The power angle can be changed by varying injection at either bus, e.g. generation or load changes.

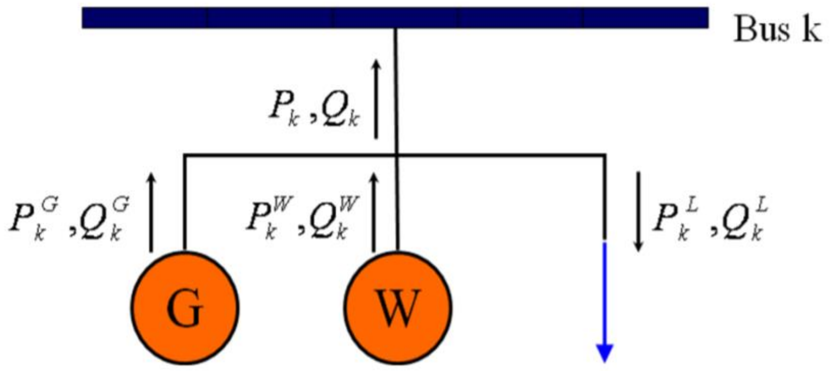


Fig. 4 Example of injection for congestion management

Each bus k is categorized into one of the following three bus types:
PQ buses - here, the real power |P| and reactive power |Q| are specified. It is also known as Load Bus.
PV buses - here, the real power |P| and the voltage magnitude |V| are specified. It is also known as Generator Bus.
Slack bus - to balance the active and reactive power in the system. It is also known as the Reference Bus or the Swing Bus.
Reference to Figure above, consider injection process at Bus "k" where Active and Reactive Power produced by Generators and Renewable Generators. Also load at bus "k" consumes amount of power to be deducted from injection part.
So Active Power and Reactive Power at Bus k are given by equations:

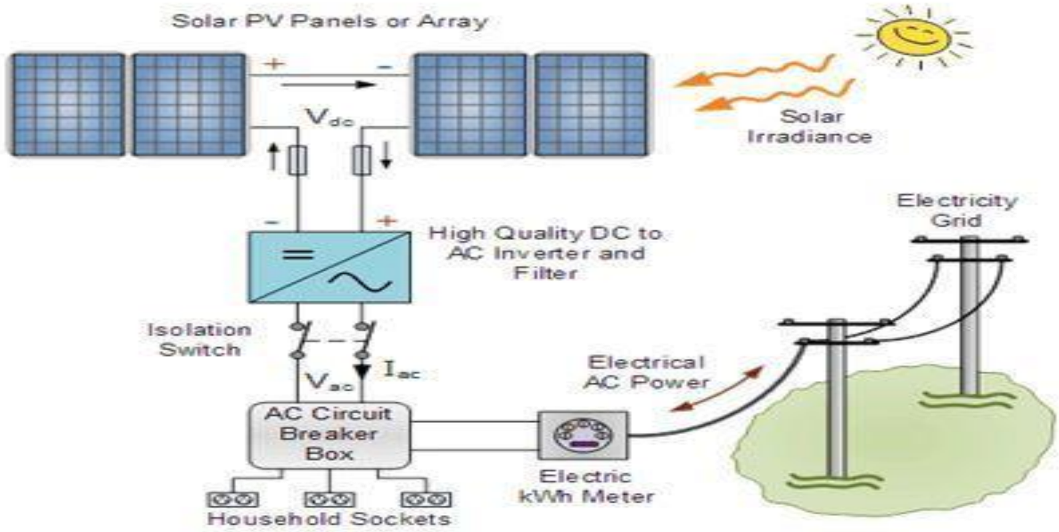
$$\boldsymbol{P_k = P_k^G + P_k^W - P_k^L}$$

$$\boldsymbol{Q_k = Q_k^G + Q_k^W - Q_k^L}$$

Additional Resources for Smart Energy Management in Smart Cities

Solar PV Generation

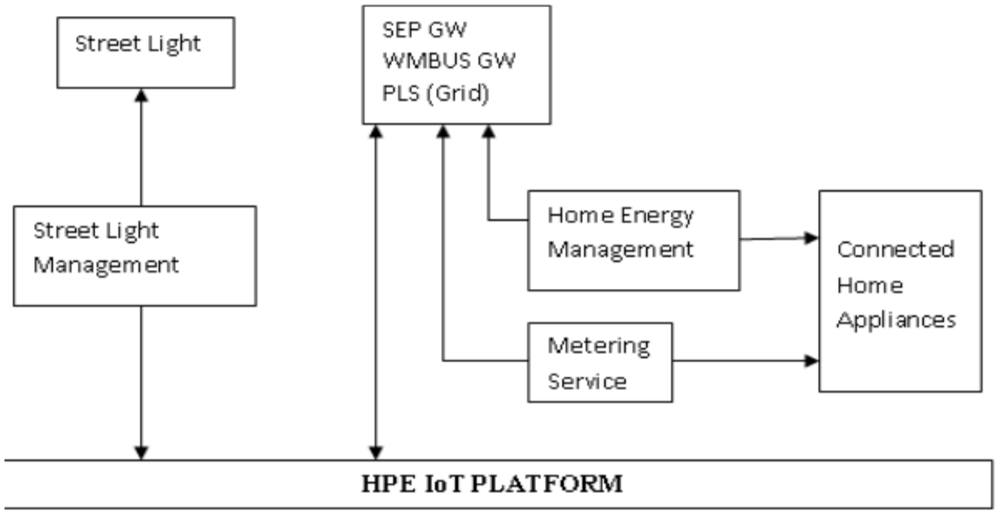
To enable Smart Electrical Energy supply for the consumers in the Smart City existing power system structure (vertical organization of transmission and distribution network) needs to be rearranged in more meshed type according to deregulation and distributed generation concept. This topic has been treated in many scientific papers and books . Clean energy supply is possible only if renewable energy sources (RES) are considered. Within the Smart City, in densely populated areas (down town), huge wind turbine, large-area hydro power plants, deep well geothermal plants or bio-gas production plants are not appropriate for electricity generation. On the other hand, light solar photo-voltaic (PV) structures can be easily mounted on the public buildings´ roofs, on top of commercial or sport centres, shopping malls, industry halls, over the open-space on parking lots, etc. Roof-top PV plants may be used as in-grid or off-grid PV systems. In the first case, all produced energy is generated into the existing (public) electrical network, without any storage or in-house usage. Off-grid systems generate energy for self consumption and battery storage, with or without possibility to handover the surplus of the electricity into the public grid. The former systems are more convenient, as they require lower investment and maintenance costs. A schematic of such system presenting an actual PV system is given in Fig. 2



Smart Lighting

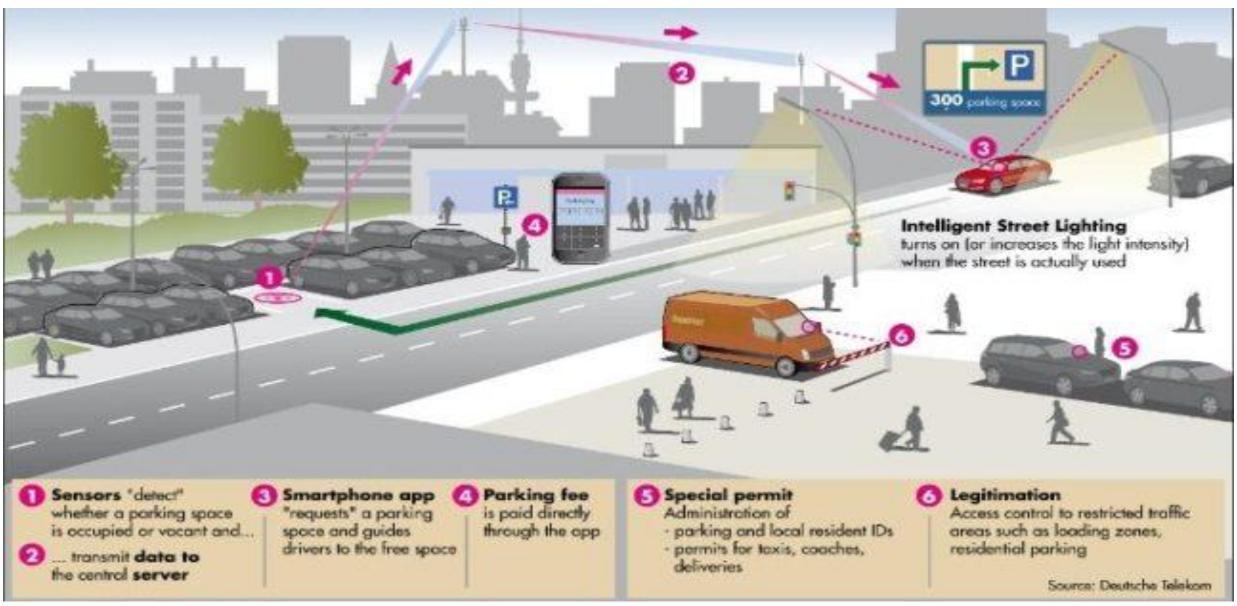
Increased environmental and regulatory pressures toward energy efficiency increase the cost of energy. Many Countries are trying to improve their street lighting operations and infrastructure. Street lighting consumes as much as 40 percent of energy consumption. Legacy High Pressure Sodium (HPS) lights and their supporting infrastructure are particularly inefficient and often operate for up to 12 hours a day at full intensity. With HPS, streetlights often having a short life span— around five years, so it's not uncommon for operators to replace approximately 20 percent of these lights each year. . This leads to unpredictable services and maintenance costs. To address these issues, many operators are moving to new, energy-efficient LED-based streetlights which enable lower energy use coupled with providing IP connectivity and IoT sensors into the lighting infrastructure to provide remote management and monitoring. Smart street lighting requires new, smart/connected luminaries and power units (ballasts) to be fitted Smart street lighting requires new, smart/connected luminaries and power units (ballasts) to be fitted. In collaboration with our partners, the HPE Universal IoT Platform is capable of managing a smart lighting solution that leverages both HPS lights and new LED-based lights.

.



Smart Parking Concept

Today, smart parking includes total control of all parking spaces with street displays or mobile phone applications about location and number of available free parking places. Advanced applications have short-time booking and guidance to the free parking place with lightning control inside the parking lot. Also, security monitoring and car finder features are available . Fig. 5 presents a scheme of one of such systems available on the market.



References:-

- Kuper, A. and Kuper, J., eds (1996) The Social Science Encyclopedia, 2nd edition. London: Routledge.
- R. Rifkin et. al, "A third Industrial Revolution Master Plan to Transition Rome into the World's First Post-Carbon Biosphere City", Jeremy Rifkin Group, Rome, 2010.
- Z. Morvaj, L. Lugaric, B. Morvaj, "Smart cities, buildings and distribution networks - perspectives and significance for sustainable energy supply", presented at 2nd Croatia CIRED Conference, Umag, Croatia, 2010.
- [Communication from the Commission to the Council and the European Parliament: Critical infrastructure protection in the fight against terrorism [COM(2004)702 final], Brussels, 2004. [5] R.T.Watson, M.C.Zinyowera, R.H.Moss, „The Regional Impacts of Climate Change: An Assessment of Vulnerability", Cambridge University Press, 1997, p. 53
- European Comission, Covenant of Mayors [Online] Available: http://www.eumayors.eu/
- The European Electricity Grid Initiative (EEGI) Roadmap 2010-18 and Detailed Implementation Plan 2010-12, Brussels, May 25, 2010
- PowerWorld Corporation, User's Guide for PowerWorld Version 14, South First Street Champaign, IL 61820 (2001)
- A. Moderink et al., "Simulating the effect on the energy efficiency of smart grid technologies", in Proc. 2009 Winter Simulation Conference, pp 1530-1541
-] A. Moderink et al., "Simulating the effect on the energy efficiency of smart grid technologies", in Proc. 2009 Winter Simulation Conference, pp 1530-1541
- **http://esa.un.org/unpd/wup/highlights/wup2014-highlights.pdf**
- **https://www.intechopen.com/books/smart-**
- http://w3.siemens.com/topics/global/en/intelligent-infrastructure/Pages/intelligent-infrastructure.aspx

.