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University of Lille

Laboratory of Civil and Geo-Environmental Engineering

Discipline: Civil Engineering

By

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Transformation of the Education City (Doha - Qatar) into a Smart City

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Résumé

Ce travail de thèse a pour objectif d'établir une solution pour la transformation du campus de l'Education City (Doha, Qatar) en une ville intelligente. Ce campus est construit sur 14 km^2 avec près de 80 bâtiments. Il comporte des infrastructures pour le transport, l'eau et l'énergie.

La première partie du travail de thèse a compoté une synthèse bibliographique des travaux réalisés sur la transformation des sites existants (quartier, campus,..) en ville intelligente. Ce travail a permis de déterminer la méthodologie à suivre et les éléments permettant la transformation en ville intelligente.

La seconde partie a comporté la collecte des données sur le campus et leur intégration dans un SIG. L'analyse de ces données a permis d'identifier les besoins et les défis des infrastructures et de leur gestion.

La troisième partie a porté sur la transformation des services d'eau (potable, irrigation, assainissement, protection contre le feu, système de refroidissement) en système intelligent.

La 4ème partie a porté sur la transformation du système électrique en un système intelligent.

Abstract

The aim of the thesis work is to establish a solution for the transformation of the Education City campus (Doha, Qatar) into a smart city. This campus is built on 14 km^2 with nearly 80 buildings. It includes infrastructures for transportation, water and energy.

The first part of the thesis compiled a bibliographical summary of the work that done on the transformation of existing sites (neighborhood, campus, ..) into a smart city. This work allowed to determine the methodology to follow and the elements allowing the transformation into a smart city.

The second part involved data collection about the Education City and integration into a GIS system. Analysis of these data allowed to identify the needs and challenges of infrastructures and their management.

The third part focused on the transformation of water services (drinking, irrigation, sanitation, fire protection, cooling system) into intelligent system.

The last part concerned the transformation the electrical system into an intelligent system.

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General Introduction

General Introduction

Education City, Doha

This research concerns the transformation of the Education City into a Smart City. This city is an initiative of Qatar Foundation for Education, Science and Community Development. It covers 14 km^2 and hosts educational facilities from school age to research level and campuses of international universities.

The Education City was built on an area with existing infrastructures. It is compozed of 2 zones (North and South) with indepednt infrastructures and facility management sytems. Each zone includes Center Plants, EDC (Electrical Distribution Centers) and Utility Tunnel, which are independent. Utilities are organized into two groups: (i) The water system which uses central plants and the Utility Tunnel for water services (drinkin, irrigation, sanitation, storm water and chilled water) and (ii) the eclectrical system which uses EDC (Electrical Distribution Centers) and substations for the electrical supply. Both water and electrical consumptions are collected manually. The Facility Management System includes a large number of systems and applications. An integrated Facility Management System is required for data collection, data analysis, decision-making, performance analysis, asset management, operation optimization, safety and optimal investement.

Smart City and Smart Grid Concepts

The Smart City and Smart Grid concepts are based on the application of the digital technology to urban system. These concepts constitute a great opportunity to build inclusive cities with improved urban systems efficiency and safety.

The implementation of the Smart City concept constitutes a long process, which concerns all city stakeholders (city government, city services, citizens, private sector and urban services providers). It includes the following steps:

- Diagnostic of the current situation of the city; it should cover legal, economic, social and government issues a establish a Road Map for the Smart City implementation.

- Establishment of actions plan, which is composed of a set of actions to be carried; for each action, this plan provides the objective, sub-actions, calendar, quality control, milestones, deliverable,
- Implementation of the smart solution, which includes construction of urban information system, smart monitoring, data transmission, data storage, data analysis using engineering and Big Data tools and graphic visualization.
- Assessment of Smart Solution for the evaluation of the Smart City impact through technical tools and end-users' feedback. The sustainability of the solution should also be addressed.
- Maintenance of the Smart solution to ensure a high operating level of the smart city solution.

This thesis includes 4 parts.

The first part focuses on the literature review of researches and achievements in the fields of the Smart City and Smart Grids. It presents the city challenges such as the population growth, energy consumption, greenhouse emission and climate change. Then it discusses the digital mutation and its potential role in transforming the City into a Smart City and the conventional Electrical Grid into a Smart Grid.

The second part describes the Education City, which is used as a support for this research. It presents analysis of the governance of this city, the master plan for utilities and the Facility Management. This analysis allows to establish the challenges for the water and energy services.

The 3rd part concerns the smart transformation of the water system, which ensures services related to potable water, irrigation, chilled water, storm water, foul water and fire protection. This system was built according to the requirements of the construction time. It suffers from fragmented management, lack of monitoring, lack of cooperation between central plants and campuses. The proposed Smart Water service includes:

- Integrated platform for the management of water services
- Integrated information system, which includes asset data as well as operating data
- Data analysis tools, including engineering and Artificial Intelligence tools
- Data visualization and system control

The last part concerns the trasnsformation of the electrical system, which was built by layer to meet the development of the Education City according to the requirements of the period of construction. This system focuses on the operational part with demand estimated from buildings and facilities design. Consumption metering is still manual, which does not allow to know exactly the buildings demand. The system does not include renewable energy. With today's requirement concerning sustainability, the transformation of the electrical system into a smart system becomes a “must”. This transformation will ensure an optimal management of the electrical power through energy consumption scheduling as well as the use of storage le and renewable energy capacities. The system will allow also to improve the reliability and safety of the grid by a rapid diagnosis of electrical faults as well as the implementation of a resilience strategy.

Chapter 1: Literature review

2. Chapter 1: Smart City and Smart Grids: Literature review

This chapter presents a literature review of researches and achievements in the field of the Smart City and Smart Grids. It starts by a presentation of the city challenges such as the urban population growth, the complexity of urban infrastructures and the management of urban infrastructures. The chapter presents also the digital transformation and its potential role in the transformation of the City into a Smart City. Finally, the chapter presents the development of the Smart Grids concept for the modernization of the electrical grids by combining the digital technology with the electrical power technology.

2.1. City challenges

2.1.1. Urban population increases

According to the World Urbanization Prospects of the Unites Nation in 2011, currently over 50% of the world's populations live in cities. Estimates show that by 2030, this number will rise to 60%, and then to 70% by 2050. Urbanization is increasing exponentially. Currently, 70% of the global energy demand comes from urban areas, also making up for 80% of greenhouse gas emissions (GHG).

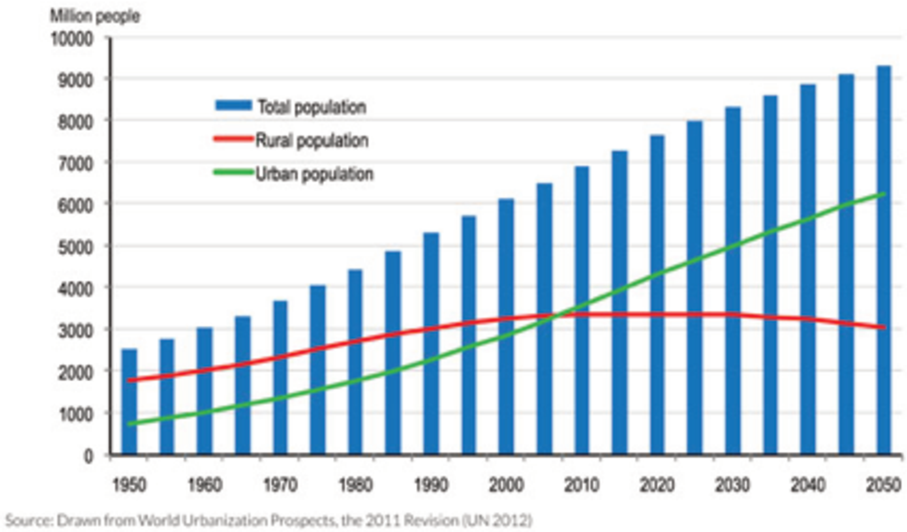

Figure 1.9: Urban population growth in the world (Source UN, 2015, World Urbanization Prospects)

1.1.2 The city: complex and living system

The quality of any city is related to the quality of its services, which lie on complex urban infrastructures. These infrastructures are built for a given service time, which depends on the initial investment, operating conditions, maintenance and modernization.

There are similarities between the city and a human body. Both include infinite link of systems and networks. If one system is damaged, it directly affects the overall efficiency and capacity of the entire body. They both require balance among their natural resources to maintain survival, and to ensure their sustainable future. The daily life of a regular individual has become more harmful to the environment, when considering the urban hazards (natural, industrial, economic, social, cyberattack..).

The City, as a human body, operates efficiently when all actors are functioning in harmony. If one area is damaged, it directly affects the urban systems efficiency. Control, maintenance and monitoring of urban systems and networks allow identify the weaknesses, limitations and detect any gaps in the overall operating.

Today, urban services are organized in silos with weak interaction, and in some cases without any interaction. This “old” system is maintained, because of cultural and professional conformism and a lack of awareness of the impact on this organization on the efficiency and security of urban services and infrastructures.

The emergence of the digital transformation constitutes an excellent opportunity for the transformation of this “non-cooperative” organization mode into fully-cooperative mode. In the following section, we will present the opportunity of the digital revolution in the transformation of the City.

1.1.3 Urban infrastructure management

With the increasing unban concentration, cities are submitted to large challenges, in particular:

- How to ensure urban services such as transportation, water supply, sanitation, energy supply and management of solid wastes in an optimal and safe way.

- How to ensure resilience of urban infrastructures and services regarding natural, human and industrial hazards?
- How to involve citizens in the sustainable urban development?

The capacity of cities to address these challenges depends on the quality of urban infrastructures. In developed countries, cities have large urban infrastructures, which were mainly built in the 20th century. The maintenance and upgrading of these infrastructures need large financial investment. In less developed countries, cities need huge investments for the construction of urban infrastructure.

The management of urban infrastructures is crucial for urban development. Infrastructure management requires a good knowledge of the infrastructures' assets. The use of the Geographic Information System (GIS) constitutes an excellent tool for an efficient management of the infrastructures. Urban system monitoring is also required to understand the operating performances of turban infrastructures.

2.2. Urban Digital transformation

2.2.1. Digital transformation (IoT & smart sensors)

According to the United Nation Report "The New Digital Revolution: From the consumer Internet to the industrial Internet" (2014), it was estimated that 3.6 billion people around the world were subscribers to mobile phone services; 2.923 billion individuals, (40%) of the population, used the Internet; over 3 billion fixed and mobile broadband subscriptions. These key figures summarize the vertiginous expansion of the digital transformation in our life (Figure 1.2). Today, we live in a totally connected world.

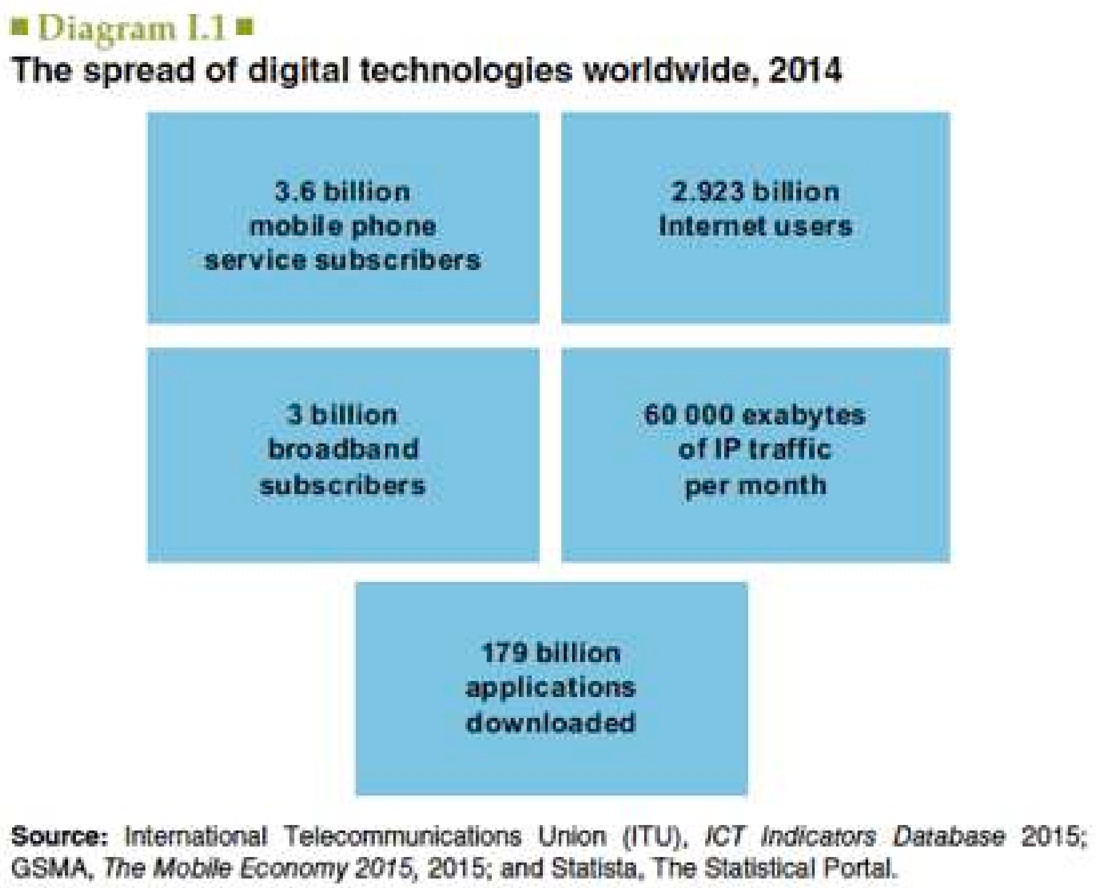

Figure 1.2 Use of digital technology in the daily life (worldwide, 2104).

The digital revolution is also derived by the development of Internet of Things (IoT). According to Wikipedia "The internet of things is the network of physical devices, vehicles, buildings and other items—embedded with electronics, software, sensors, actuators, and network connectivity that enable these objects to collect and exchange data. The IoT allows objects to be sensed and controlled remotely across existing network infrastructure, creating opportunities for more direct integration of the physical world into computer-based systems, and resulting in improved efficiency and economic benefit". Thanks to this technology, every object "Thing" could be connected. It could transmit and receive data. In addition, it can also store and analyze data and operate actions. According to CISCO, the number of IOT in the world will reach 50 billion (Figure 1.3).

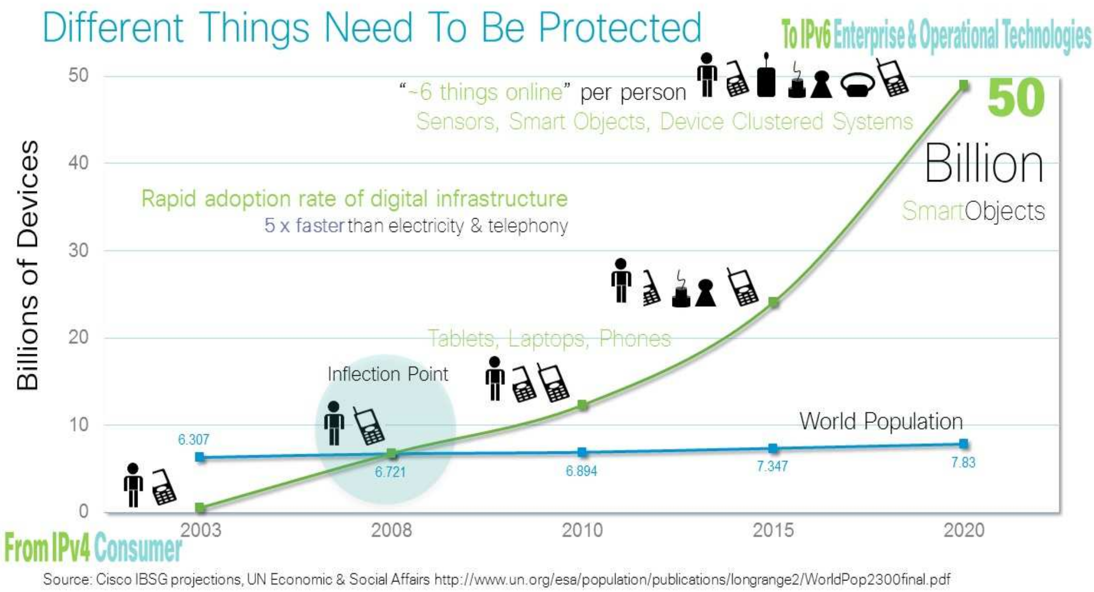

Figure 1.12: Perspective of the Internet of things (IoT) development (source CISCO)

Smart sensors include the following components (Figure 1.4):

- A central unit with a microprocessor to manage tasks.
- Battery:
- Transceiver, which collects data.
- Memory to store data
- Communication module for data transmission.
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Smart sensors can conduct monitoring of physical system through recording physical parameters as well as analysis, storage and communication with other sensors. Embedded software allows to operate complex tasks such as devices control.

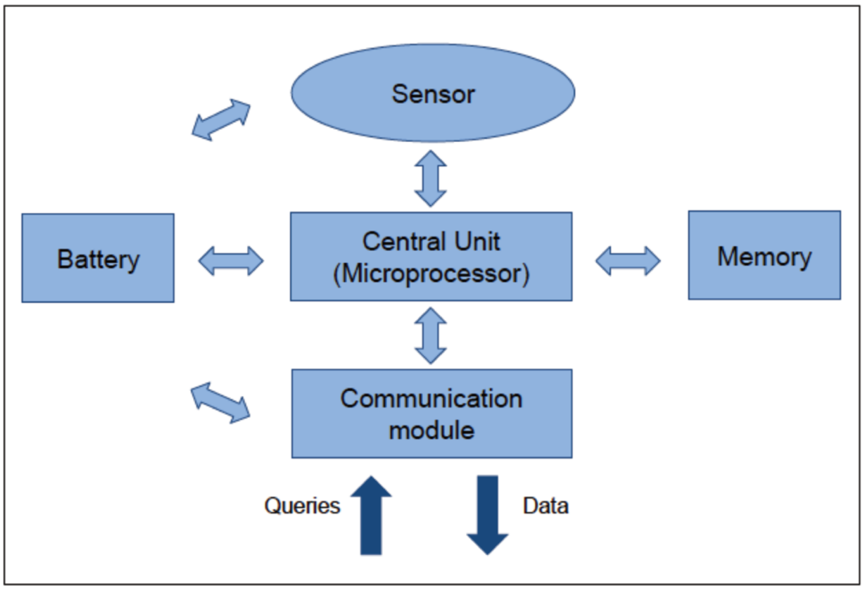


Figure 1.4: Architecture of smart sensors (OECD Report - Smart Sensor Networks: Technologies and Applications for Green Growth[1])

2.2.2. Smart City

Concept

The Smart City concept aims at using the digital technology and social innovation for an optimal and safe management of urban systems with a special focus on life quality as well a friendly environment.

Smart City concept concerns interdisciplinary approach. Anthopoulos (2015) classified the academic researches on smart cities into four domains: Information and Communication Technology (ICT), eco city, urban planning and creative industry. To these domains we should add important issues such as urban infrastructure engineering, economy, management, safety and urban governance.

The European Innovation Partnership on Smart Cities and Communities (EIP-SCC) aims at "Striving a triple bottom line gain for Europe: a significant improvement of citizens' quality of life, increased competitiveness of European industry together with contribution to EU's

[1] [1] https://www.oecd.org/sti/ieconomy/44379113.pdf

20/20/20 energy and climate targets. Figure 1.5 shows the Strategic Implementation Plan of the EIP-SCC. It includes three 'vertical' domains:

(i) Sustainable urban mobility.
(ii) Sustainable districts and built environment and
(iii) Integrated infrastructures and processes across energy, ICT and transport.

The strategic plan covers eight "horizontal" themes: citizens, policy & regulations, integrated planning, knowledge sharing, matrics & indicators, open data, standards and business models.

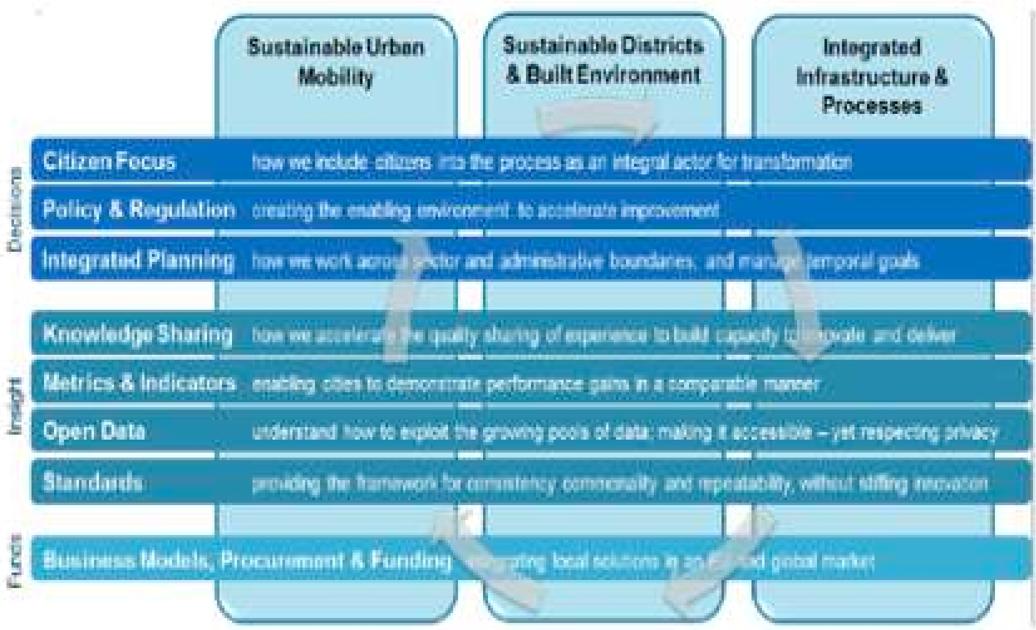


Figure 1.5: Strategic Implementation Plan of the European Innovation Partnership on Smart Cities and Communities (EIP-SCC)[2]

The Focus Group "Smart Sustainable Cities" of the International Communication Union adopted the following definition for Smart City "A smart sustainable city is an innovative city that uses information and communication technologies (ICTs) and other means to improve

[2] http://ec.europa.eu/eip/smartcities/files/sip_final_en.pdf

quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social, environmental as well as cultural aspects". Figure 1.6 summarizes the vision of ITU for the Smart City. It is viewed as a system of subsystems, which address different smart sustainable urban services such as waste management, buildings, tourism, health service, safety, emergency, energy, water, transport, education and e-government.

Figure 1.6 : Smart City Concept of ITU (Source ITU)

Figure 1.7 presents the IBM concept for Smart Cities. It covers the following areas:

- Management concerning public safety, government and agency administration, city planning and buildings.
- Urban infrastructures (water, energy and transportation).
- People with particular concern, healthcare and education.

Figure 1.8 shows Huawei's Smart City concept. It concerns the following areas:

- Smart government.
- Smart life,
- Smart industry.

The Smart City concept of Siemens focuses on energy optimal management. According to Siemens, "smart cities" is characterized by power grids that ensures balance between electrical supply and demand. It covers buildings that learn occupants' energy needs, respond to changing weather conditions, and maximize energy efficiency.

Figure 1.7: IBM Concept for Smart Cities (Source IBM[3])

[3] http://www.ibm.com/smarterplanet/us/en/smarter_cities/overview

Figure 1.8 : Huawei Smart City Concept - (Source HUAWEI[4])

Smart Monitoring

The Smart City is based on real-time monitoring of urban infrastructure including water and energy networks, transportation infrastructures and buildings (Buchholz and Styczynski 2014, El-Hawary 2014, Momoh 2012, Tuballa and Abundo 2016). Monitoring includes smart sensors and actuators connected via wired and wireless communication networks. Sensors readings are stored in large data sets together with information on the infrastructure asset and other useful data such climate information, traffic, users' profiles and consumptions. The data could also be enhanced by images, videos and audios resulting in the construction of urban Big Data (Chen et al. 2014, Mayer-Schönberger and Cukier K 2013).

Implementation of the Smart City concept

[4] https://www.google.fr/#q=huawei+smart+city

The implementation of the Smart City concept constitutes a complex and long process, which concerns the city stakeholders: City government, city services, citizens, private sector and urban services providers.

Figure 1.9 summarizes the steps for the Smart City implementation.

The first step concerns the diagnostic phase, which is the vital part of the smart city transformation process. Prior to implementing smart city solution, the challenges and goals of the City should be established. Analysis should also cover the effectiveness of the Smart City solution to meet the City challenges. This phase should also analyze legal, economic, social and government issues of the Smart City Solution. This phase results in establishing a "Road Map" for the Smart City implementation.

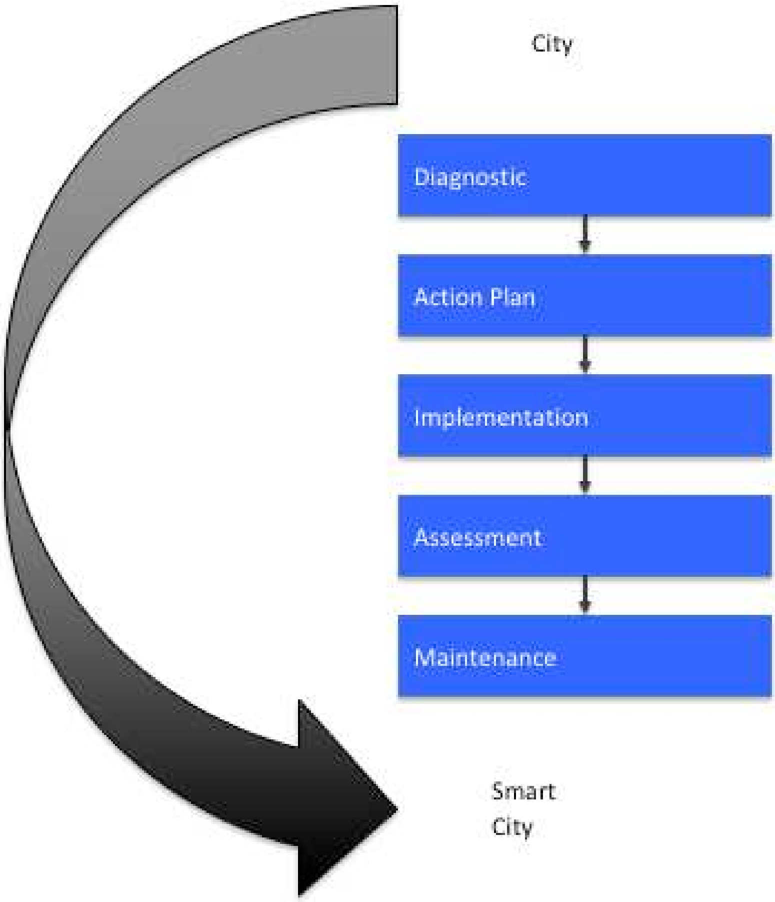


Figure 1.9: Steps for the Smart City Implementation (Sakr, 2017)

The second step concerns the action plan, which is composed of a set of actions to be carried. For each action, it gives the objective, sub-actions, calendar, quality control, milestones, deliverable,

The 3rd step concerns smart solution implementation. It includes construction of urban information system using GIS and BIM tools, smart monitoring, data transmission, data storage, data analysis using engineering and Big Data tools and graphic visualization.

The 4th step refers to the assessment of Smart City Solution. It concerns evaluation of the Smart City impact through technical tools as well as end-users' feedback and economic return. The sustainability of the solution should also be addressed.

The final phase in the road to smarter cities concerns the "maintenance". This phase does not concern a short period of time. Maintaining the smart city solution is necessary to ensure the a high operating level of the smart city solution.

2.3. Smart Electrical Grid

2.3.1. Traditional Electrical system

Electric power system is a network that includes electrical machines, lines and mechanism to generate electricity and supply to customers. The electrical grid is composed of interconnected generators and networks, that generate, transport and distribute electricity to habitation, commercial buildings, industries, hospitals and other urban services such as public lighting and transportation. The electrical power system is generally organized into three sectors: Generation, Transmission and Distribution.

The electrical generation uses generators to convert energy from various sources to electric power at a given voltage. For economic dispatching, a control center collects the generators' output values and controls the generators to meet the demand at the lowest cost. In the case of a sudden change in the demand, the generator frequency could experience sudden variation.

The electrical transmission system ensures the transmission of the electric power to long distances through high-voltage (HV) using overhead lines or underground cables. The transmission voltage could vary between 33 and 500 kV. The voltage levels are determined on the basis of the amount of power and the transmission distance. The electrical transmission grid is meshed to ensure the continuity of the power supply in case of local fault. In meshed grids, lines are generally loaded at 50 % of their capacity to allow continuity of supply after local fault. In addition to supply reliability, the meshed network provides benefits such as broad choices of generating plants, reduction in reserve capacity of generators, diversity of load demand (Islam et al. 2013).

The electrical distribution system ensures customers supply. It includes transformers to transform the electrical voltage to the required supply voltage (220 V, 440 V, or higher for commercial or industrial uses).

2.3.2. Electrical grid challenges

Since electricity concerns vital issues of the daily life, the industry and services, reliability is one of the major challenges of the electrical system. It consists in the capacity of the electrical system to deliver electrical power to consumers within accepted standards. Faults in the electrical system are mainly related to loss of voltages (Kueck et al. 2004). It can be evaluated by frequency and duration of interruptions as well as magnitude of adverse effects on the electric supply. Power quality may be defined as the measures, analysis and improvement of bus voltage to maintain that voltage at rated voltage and frequency to meet the requirements of the consumers' devices ((Kueck et al. 2004).

Protective system is used in the electrical system to protect electrical generators, transformers, lines and equipment against faults. The purpose of this system is to quick isolate the fault, so that the system can continue power supply. The protection system prevents personnel injuries and equipment damage. It also minimizes power interruptions, impacts of faults and fault-related disturbances on the system.

The electrical grid faces also the challenges of ageing infrastructure, continued growth in demand, integration of increasing renewable energy sources, the need to improve the security of supply and the need to reduce carbon emissions.

Developing countries suffer from lack of electrical infrastructure. According to the International Energy Agency (iea) , around 1.3 billion people lack access to electricity: more than 600 million in sub-Saharan Africa, more than 300 million in India.

2.3.3. Smart Grid

Drivers and definition

The majority of the world's electricity system was built when energy was reasonably low cost and in the quasi-absence of concern for environment protection. Since minor upgrading has been made to meet rising demand, the grid still operates the way it did almost 100 years ago: energy flows over the grid from central power plants to consumers, and reliability is ensured by preserving surplus capacity (Frye 2008, Hossain et al. 2013). Consequently, today, the majority of the electrical power systems are not eco-friendly. Because of their low energy efficiency and major dependence on fossil energy, they produce high amount of greenhouse gases. In addition, they are not adapted for the integration of renewable energy and energy storage capacities. As a result, the electrical power system has been the focus of investigations to address the above challenges and for transforming the power grid into a more efficient and reliable grid. The digital transformation presents a great opportunity to achieve the goal of the modernization of the electrical grid by its transformation into a "Smart Grid".

The Smart Grid combines a number of technologies, customer solutions and addresses several policy and regulatory drivers (Hossain et al. 2013). The European Technology Platform defines the Smart Grid as "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". According to the U.S. Department of Energy, a "Smart G A smart grid uses digital technology to improve reliability, security, and efficiency of the electrical system from large generation, through the delivery systems to electricity consumers and a growing number of distributed-generation and storage resources".

Hossain et al. (2013) described the "Smart Grid" as the transparent, seamless and instantaneous two-way delivery of energy information, enabling the electricity industry to better manage energy delivery and transmission and empowering consumers to have more control over energy decisions.

Smart Grid deployment

Figure 1.10 summarizes the digital layers which should be implemented in the electrical power system for its transformation into a Smart Grid (Iea 2011). It includes the following 6 layers:

Layer 1: Wide-area monitoring and Control layer

The Wide-area monitoring and Control layer connects the generation, transmission and distribution components of the electrical system. It allows a real-time monitoring and display of power system components and performance across large geographic areas.

Layer 2: Information and communications technology integration

The Information and communications technology integration layer connects all the components of the electrical power system as well as all customers. It could include private utility communication networks or public networks. It supports tow-way data transmission for deferred and real-time operation, and during outages.

Layer 3: Renewable and distributed generation integration

The renewable and distributed generation integration layer concerns the components of the electrical power system as well customers. It offers the possibility for an efficient integration of renewable and distributed energy resources.

Layer 4: Transmission enhancement applications

Flexible AC transmission systems are used to enhance the control of transmission networks and maximize power transfer capability. It uses sensors to identify the current capability of a section of network in real time; it can optimize utilization of existing transmission assets, without the risk of causing overloads.

Layer 5: Distribution grid management

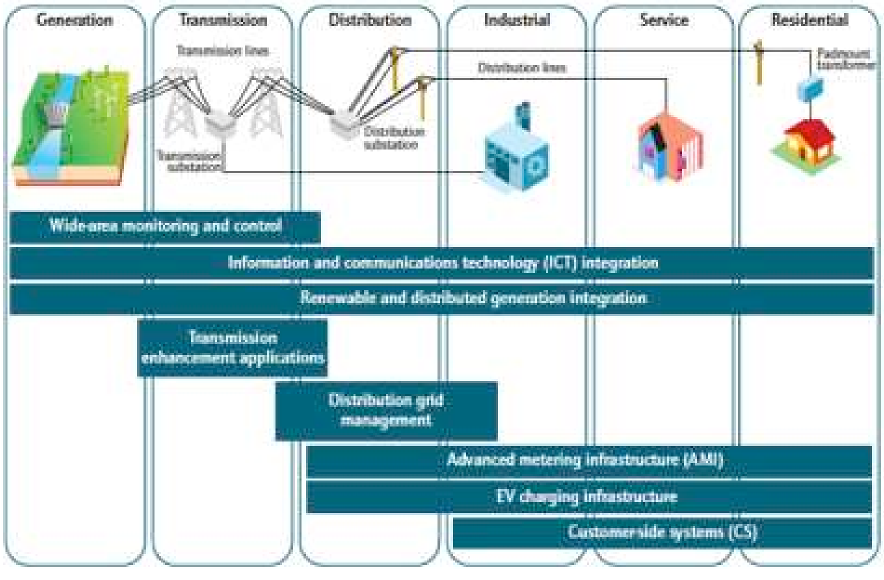
This layer uses distribution and sub-station sensing and automation to reduce outage and recovery time, maintain voltage level and improve asset management. The system processes real-time information from sensors and meters for fault location, automatic reconfiguration of feeders, voltage and reactive power optimization, or to control distributed generation.

Layer 6: Advanced metering infrastructure

This layer includes the deployment of technologies that enable two-way flow of information, providing customers and utilities with data on electricity price and consumption, including the time and amount of electricity consumed. This layer can also provide (i) Remote consumer price signals, (ii) The possibility to collect, store and report customer energy consumption data for any required time intervals or near real time, (ii) Improved energy diagnostics (iv) Ability to identify location and extent of outages and (v) Remote connection and disconnection.

Layer 7: customer-side systems

This layer includes monitoring, smart appliance, software and platforms, that enable customers to follow their consumption, to control their devices for an optimal management and to beneficiate from incentive measurements such as dynamic prices, generation of renewable energy, energy storage.



Source: Technology categories and descriptions adapted from NETL, 2010 and NIST, 2010.

Figure 1.10: Smart Grid deployment (Source iea 2011)

2.4. Conclusion

This chapter presented analysis of the literature concerning the Smart City and Smart Grids.

Today, the City constitutes a focal point in our world. It hosts around 70% of the economic activity and responsible of around 80% of the greenhouse emission. In the future, the role of the city in our life and environment will yet increase.

Since the city is a composed of complex systems, its transformation into a sustainable city (eco- and socio- friendly) requires edge- innovations that use both technology and social sciences.

The Smart City Concept is based on the application of the digital transformation in urban area. It combines both digital transformation and social innovations. This chapter presented the emergence of this concept and the methodology to be followed for its implementation.

This chapter presented also the Smart Grid concept, with a particular focus on how this concept transforms the traditional electric power system into a modern and efficient system. It presented also the digital layers to be developed for building a Smart Grid.

The literature survey shows the Smart City and Smart Grids concepts constitute a great opportunity to build inclusive cities that focus on the quality of life of citizens. However, the Smart City and the Smart Grid concepts are complex and recent. Their implementation requires to learn from large experimentations and demonstrators.

The following chapters will present the application of the Smart City and Smart Grid concepts on the Education City of Qatar Foundation. After a presentation of Education City (chapter 2), we present the application of the Smart Technology on water system (chapter 3) and electrical Grid (Chapter 4).

2.5. References

Anthopoulos, L. (2015) "Understanding the Smart City Domain: A Literature Review" In Transforming City Governments for Successful Smart Cities, Springer, SBN-10: 331903166X

Buchholz, BM., Styczynski, Z. (2014). « Smart Grids – Fundamentals and Technologies in Electricity Networks », Springer Vieweg, ISBN : 978-3-642-45119-5.

Chen M, Mao S., Liu Y.(2014) "Big Data: A Survey", Mobile Networks and Applications, Volume 19, Issue 2, pp 171–209.

El-Hawary ME. (2014). "The Smart Grid—State-of-the-art and Future Trends", Electric Power Components and Systems, 42(3–4):239–250.

Frye W (2008) Transforming the electricity system to meet future demand and reduce

greenhouse gas emissions. Cisco Internet Business Solutions Group.

Hossain MR, Oo AMT, Ali ABMS (2013) "Smart Grid" Chapter 2, Smart Grids Opportunities, Developments, and Trends,(Ed. A. B. M. Shawkat Ali), Springer, DOI 10.1007/978-1-4471-5210-1.

Iea (2011) "Technology Road Map – Smart Grid", available on line :

https://www.iea.org/publications/freepublications/publication/smartgrids_roadmap.pdf

Islam MF., Amanullah M. T. Oo, Chowdhury SH (2013) "The Traditional Power Generation and Transmission System: Some Fundamentals to Overcome Challenges" Chapter 1, Smart Grids Opportunities, Developments, and Trends,(Ed. A. B. M. Shawkat Ali), Springer, DOI 10.1007/978-1-4471-5210-1.

Kueck JD, Kirby BJ et al. (2004) Measurement practices for reliability and power quality. Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831-6285

Mayer-Schönberger V, Cukier K (2013) Big data: a revolution that will transform how we live, work, and think. Eamon Dolan/Houghton Mifflin Harcourt

Momoh, J. (2012). «Smart Grid: Fundamentals of Design and Analysis », Wiley-IEEE Press, ISBN: 978-0-470-88939-8

Tuballa ML., Abundo ML. (2016). “A review of the development of Smart Grid technologies” Renewable and Sustainable Energy Reviews, 59, pp. 710–725

UN (2015) "World Population Prospects: The 2015 Revision – Key Findings and Advance Tables" (PDF). United Nations Department of Economic and Social Affairs, Population Division. July 2015

Chapter 2: Presentation of the Education City

3. *Chapter 2: Presentation of the Education City – support of the PhD research*

3.1. Introduction

This chapter presents the Education City campus, which is used as a support for this PhD research. This City is an initiative of Qatar Foundation for Education, Science and Community Development. It is located in Al Rayyan City on the outskirts of Doha. It covers 14 km^2 and hosts educational facilities from school age to research level and campuses of international universities.

After presenting the mission and governance of the Education City (EC), the chapter provides the masterplan of the EC and describes the main components of its infrastructures: transport water and energy. It presents also the Facility Management System. Through this presentation, the chapter outlines challenges related to the Education City's infrastructures and the requirement for its transformation into a Smart City.

3.2. Mission, organisation and governance

3.2.1. Mission

The Education City was launched in 1995 as a model for sustainable development, advanced research and innovative educational system. Hence, this City is the propelling force within Qatar Foundation's scheme to catalyze human, social and economic development of the state of Qatar. The Education City has evolved in the past two decades from one varsity to a multi-varsity campus offering large opportunities for the advancement of knowledge and research across disciplines.

Within Qatar's vision 2030, a strategic mandate was attributed to the Education City to act as a driver of Qatar development with its motto "Unlocking Human Potential".

Although, exclusively a non-profit organization, since 2013 Education City has established an endowment department. The primary aim of this department is to create funds to sustain the

Education City development, with main focus on the three core areas: education, research & technology and Community Development (Figure 2.1).

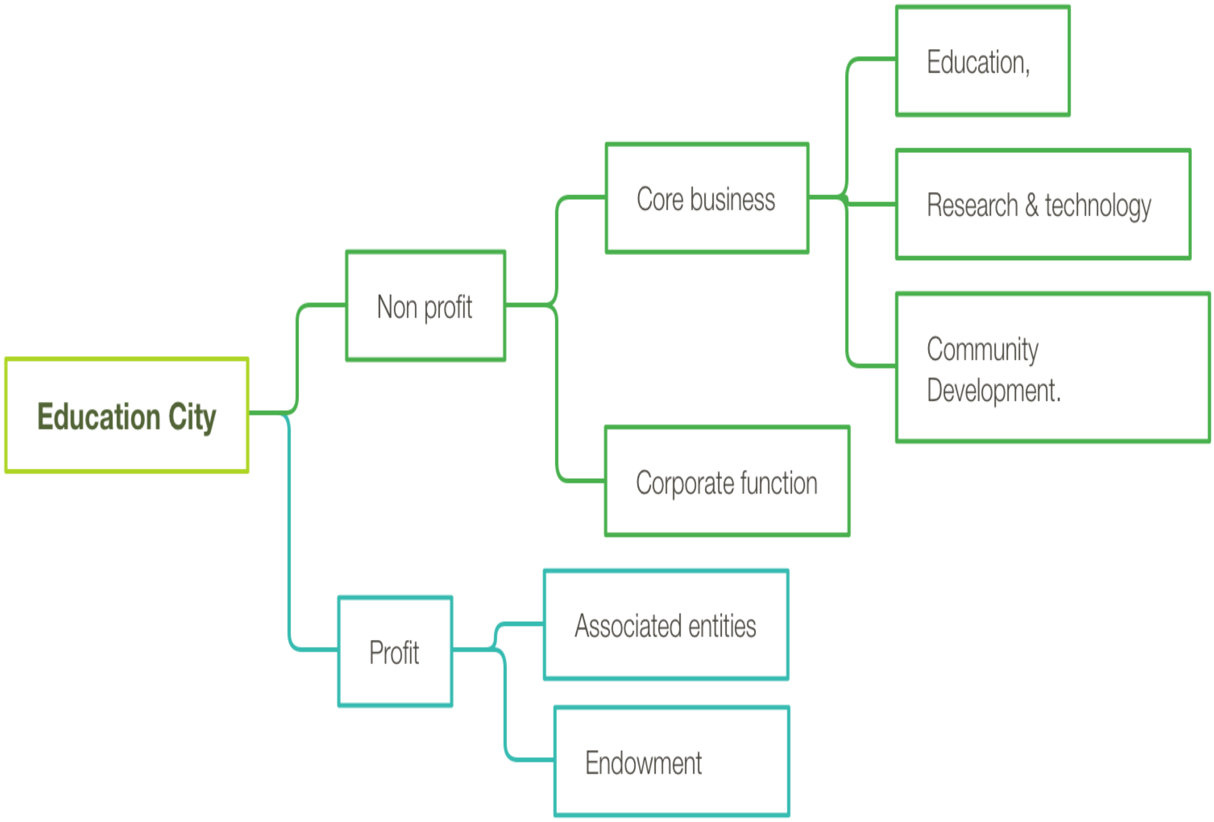


Figure 2.1 Mission of the education city

3.2.2. Organization

The Education City is organized according to its mission into 4 parts (Figure 2.2):

- Community & Development
- Universities
- Schools
- Research & Development

Table 2.1 summarizes the list of entities hosted in the Education City: 8 universities, 5 programs and projects and 5 centers. This list shows the high diversity of entities hosted by the Education City.

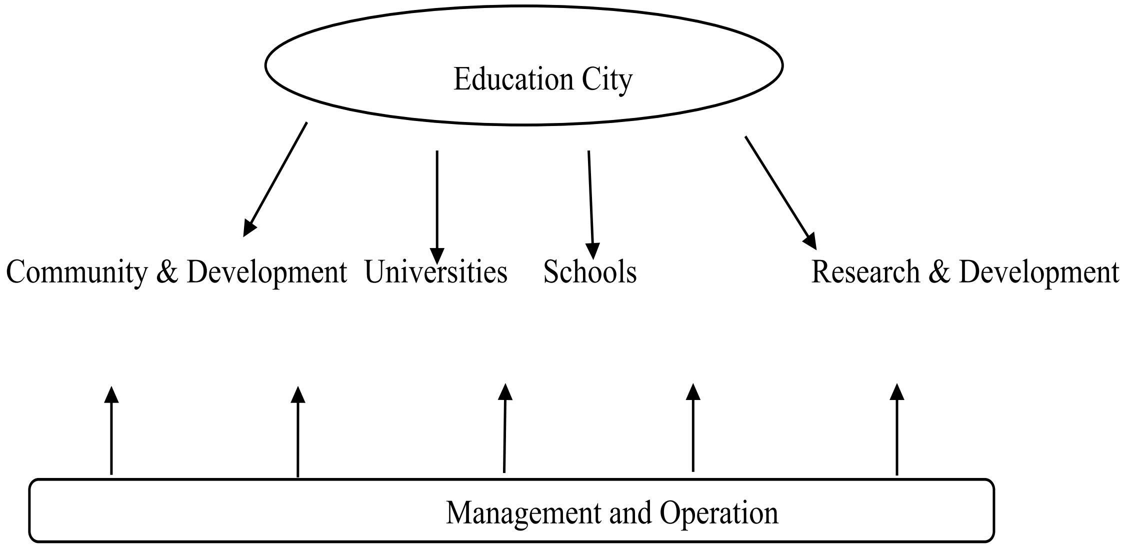


Figure 2.2 Organization of the Education City

Table 2.1 Program and partners hosted in the Education City

Partner Universities	Programs & projects	Other programs
Carnegie Mellon University	Qatar Foundation International	Amlak
Georgetown University	Stars of Science	Msheireb City
Virginia Commonwealth University	World Innovation Summit for education	Convention Center
Weill Cornell Medicine University	World Organization for the Renaissance of the Arabic Language	Qatar Solar Center
Texas A&M university	Doha International Family Institute	Sidra Medical
UCL university		
HEC Paris University		
Northwestern University		

3.2.3. Governance

Stakeholders

Figure 2.3 summarizes the list of stakeholders of the Education City. The high number of the stakeholders is due to the large diversity of hosted activities and structures. The list of stakeholders includes 3 governmental entities, the water and electrical company (Kahramma), 4 departments of the Education City and the associated partners given in Table 2.1

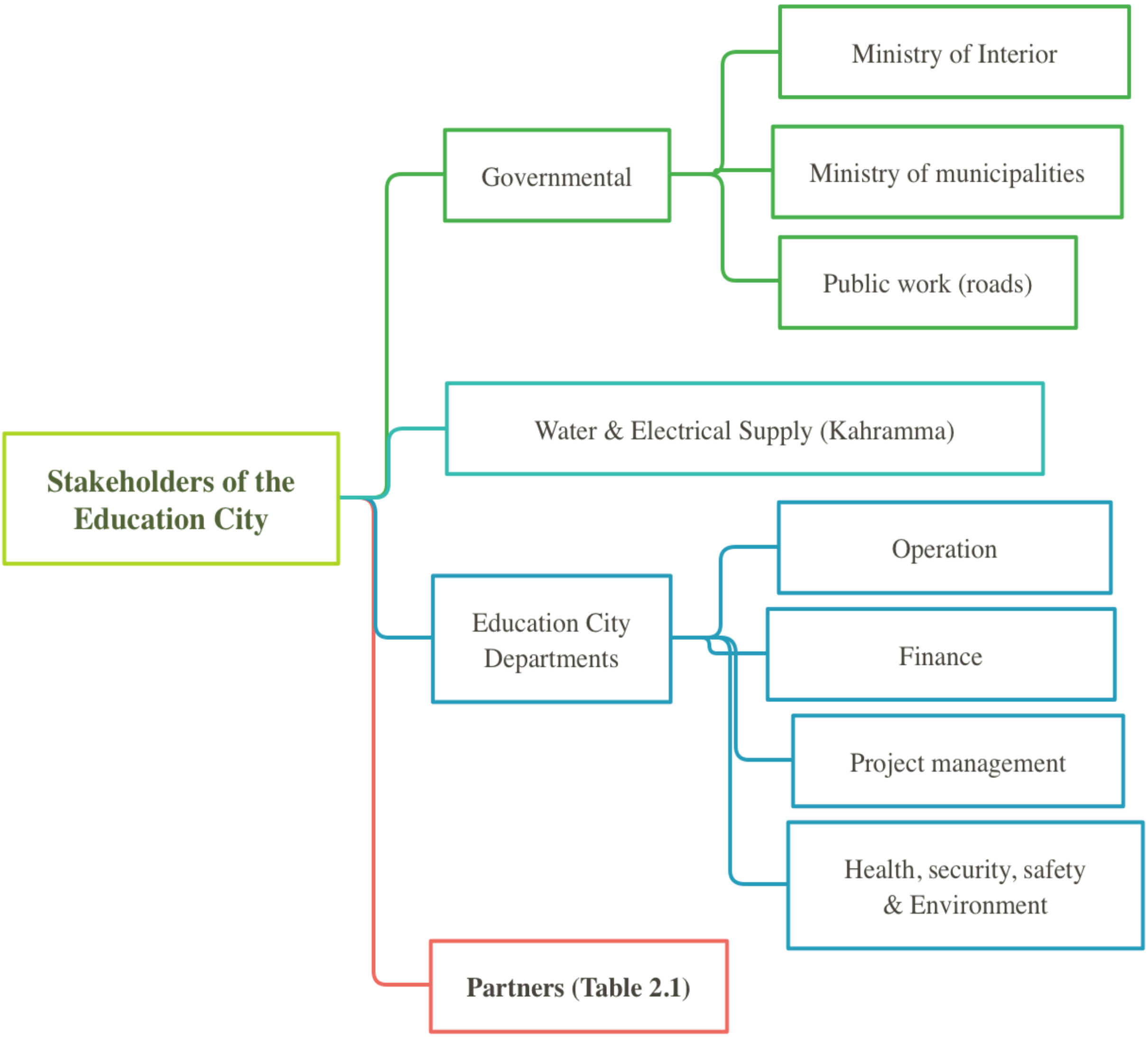


Figure 2.3: Stakeholders of the Education City

Governance

The governance of the Education City is based on three entities (Figure 2.4):

- The Founder
- The Board of Directors
- The Executive office

Qatar Foundation for Education, Science and Community Development (QF) is the founder of this project. QF establishes the vision for the Education City and, along with the State of Qatar, ensures the financial resources. The founder is supported by a Board of Trustees.

The Board of Directors supervises the implementation of the vision and strategy of the Education City. This board is responsible for the use of funds provided by the Founders and for the realization of assigned objectives. The Board of Directors is supported by an advisory board.

The Executive Office is in charge of the operational activities and daily management of the Education City.

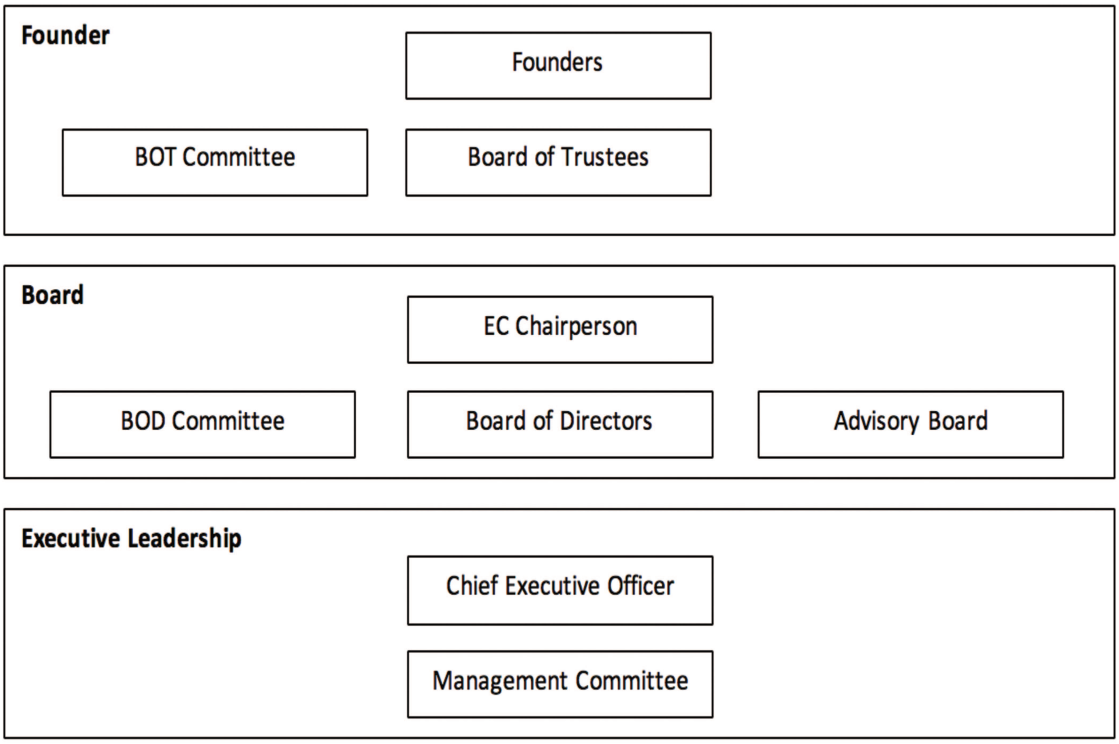


Figure 2.4: Governance of the Education City

3.2.4. Independently managed entities

The independently managed entities include partner Universit as well as Centres and Projects. They are independently managed entities. This means that the Education City authority has limited control over these independent entities, which have legal and substantial operating autonomy and the possibility to establish a business model which could not interact with the Education City facilities and services. However, the Education City authority could conduct indirect control over these entities, which must support the core mission of the Education City. Furthermore, QF has defined authority and nominated a senior hierarchy of the Education City. QF has also the possibility to enter into a management agreement via a third party agreement with any of these entities and can enter contract based ventures through a management or operating contract to implement activities. Often the agreeement between QF and the independent entities is governed by a Joint Advisory Board, which has the responsibility to advise QF’s Board of Directors.

3.3. Masterplan

3.3.1. History

The Education City was developed from an existing residential area. Existing buildings were demolished except some historical buildings. Figure 2.5 shows the evolution of the Education City site from 1960 to 2016. The original master plan was created in the early 2000s, followed by about twenty subsequent master plan revisions to meet the challenges of the rapid evolution and city growth.

As the Education City entered a new phase of development, an updated strategy for long-term growth became a necessity. The evolution of the masterplan continuously endeavored to blend with the surrounding fabric of Al Rayyan. However, the Education City has its own characteristics, offering synergies and opportunities by fostering and promoting innovation in all areas of education and innovation areas. The city has been recognized as one of the four key Metropolitan Centers stipulated by the Qatar National Masterplan for Doha Metropolitan.

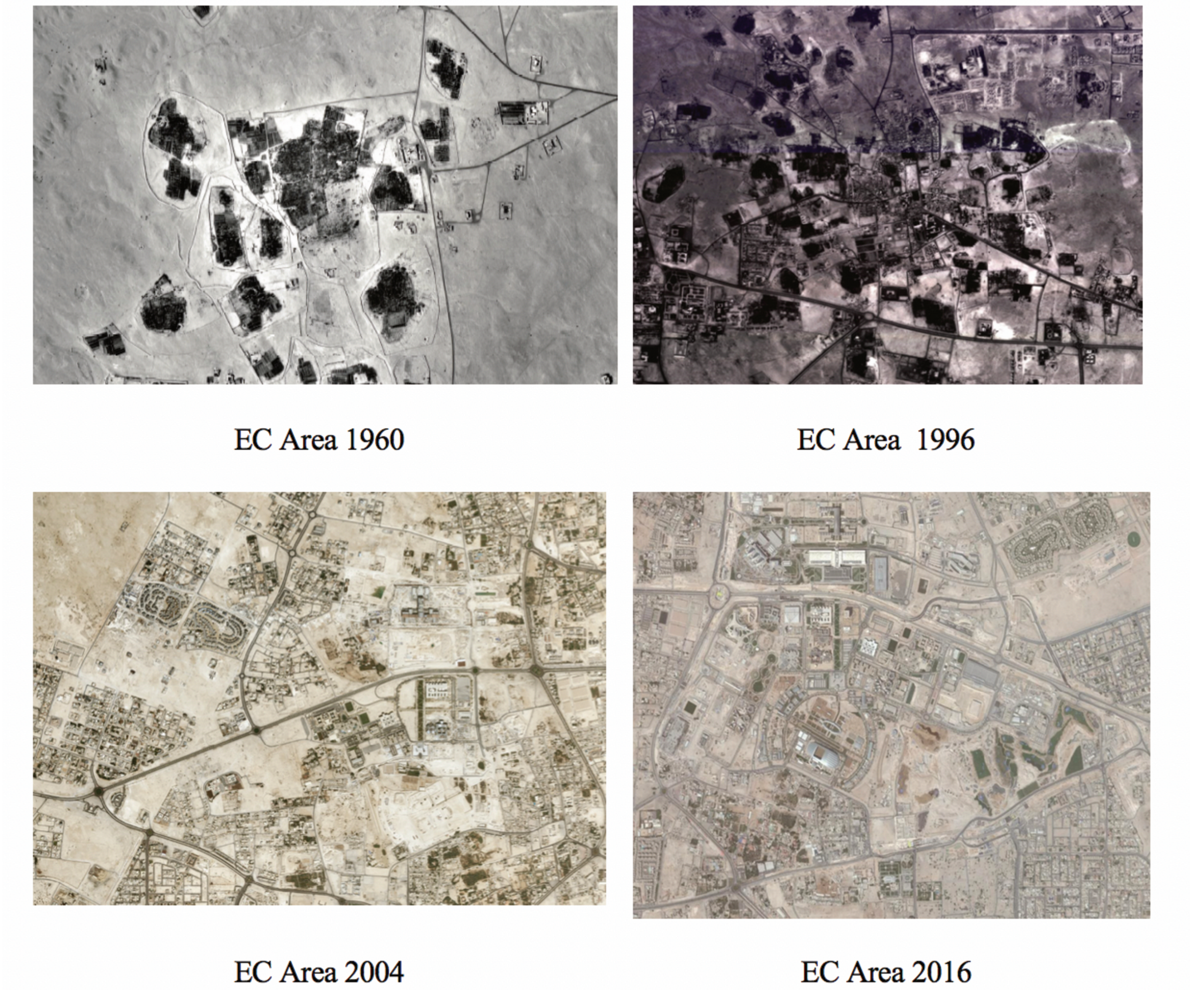


Figure 2.5 Evolution of the site of the Education City

Figure 2.6 shows the major 4 phases of the Education City development and extension. In 2002, the EC covered only 3 km^2 in the central area of the Education City, then rapidly grows in the South zone to 6.1 km^2 in 2003 and 7.5 in 2004. In 2016, it covers an area of 14 km^2 in the North and South zones.

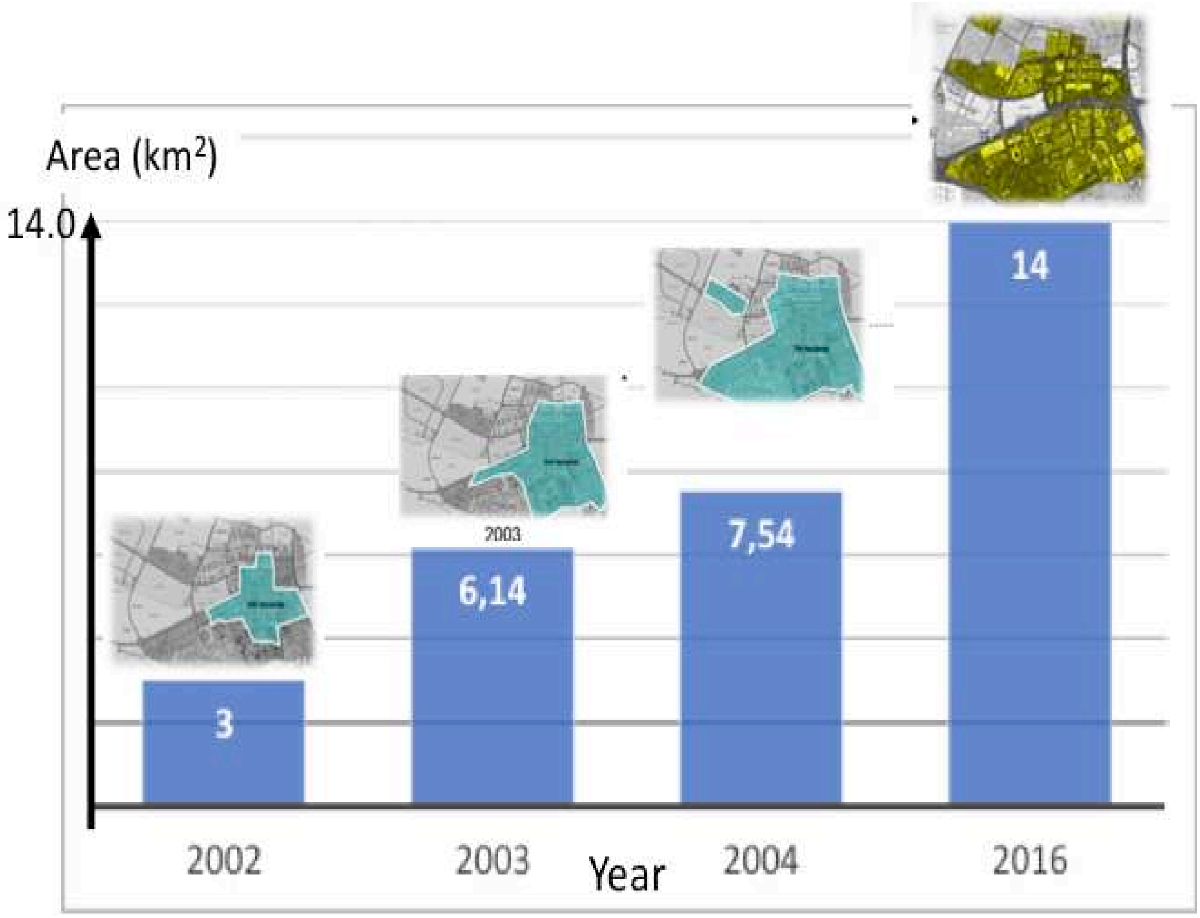


Figure 2.6 Expansion of the Education City

The Education City covers an area of around 14 km^2. Figure 2.7 shows the master plan of the Education City as revised in 2015. It is composed of 2 zones: North & South (Figure 2.8). The infrastructures of these two zones are completely independent. They are not connected. This separation is related to historical raisons.

Figure 2.7 The Master Plan of the Education City (revised in 2015)

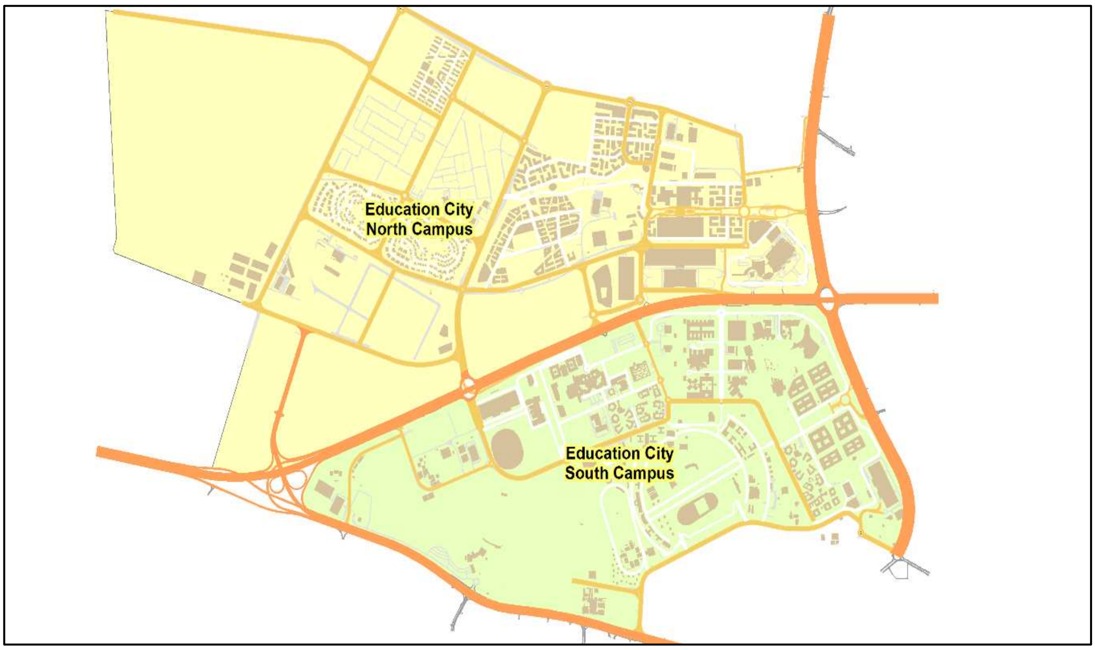


Figure 2.8 The Education City is composed of 2 zones: North and South

3.3.2. Buildings

Figure 2.2 shows the localization of buildings in the campus. We observe 2 types of repartition: isolated or by group of buildings. This repartition is due to buildings use.

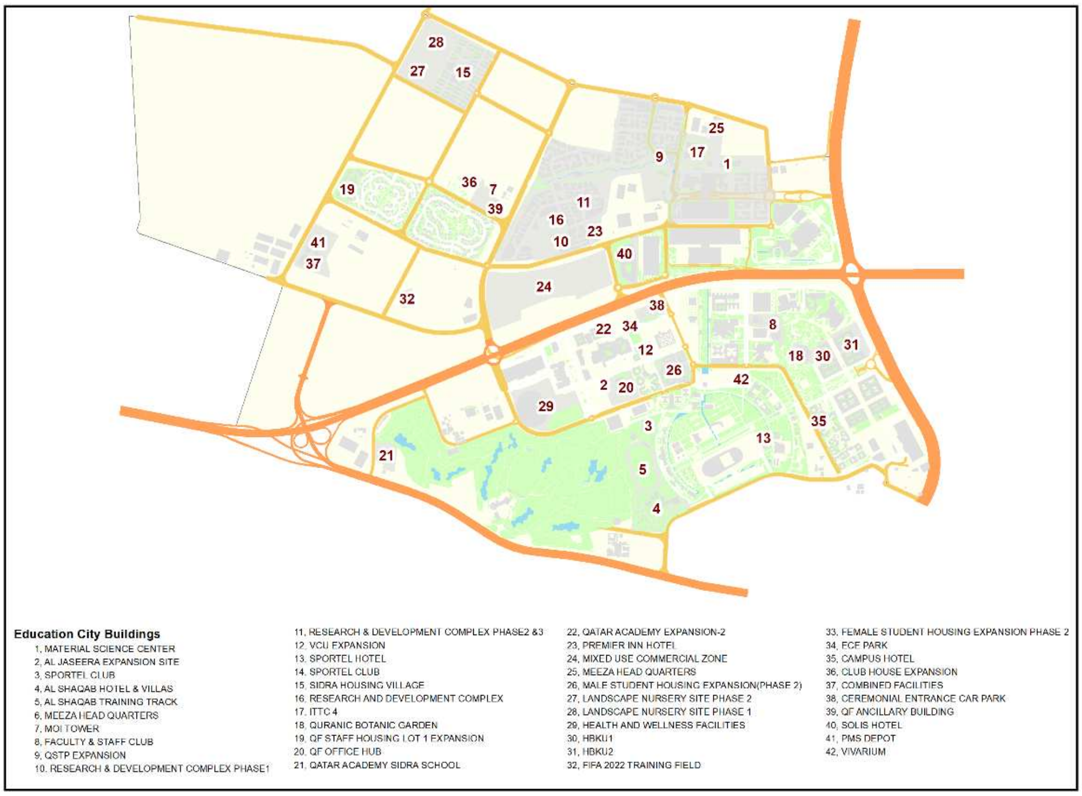


Figure 2.9 Buildings localization in the Education City

Table 2.2 summarizes the list of buildings in the Education City by destination. Buildings are used in:

- Higher Education (10 buildings)
- Pre-Education (3 buildings)
- Technology (9 buildings)
- Social services & activities (14 buildings)
- Culture, arts & heritage (5 buildings)
- Housing & hotel (6 buildings)
- Technical services (28 buildings)

Table 2.2 Buildings use in the Education City

Destination - use	Buildings	Number
Higher Education	Universities & Colleges	10
Pre-Educatioon	Education-Pre-University	3
Technology	Science and Technology	9
Social services & activities	Parks/ Public spaces	2
	Sports	4
	Club House/ Recreations	5
	Health Care	2
	Veterinary Clinic	1
Culture, arts & heritage	Museum/ Art	1
	Carousel	1
	Historic Structures	2
	Convention Centre	1
Housing, Hotel	Housing	4
	Hotels	2
Technical services	Transportation	2
	Car Park	4
	Central Plants	7
	Sub stations	13
	Communication	2
Others	Other	8
TOTAL		**82**

3.3.3. Utilities

This section provides a global presentation of the implementation and organization of utilities in the Education City. A detailed description will be provided in chapter 3 (water services) and chapter 4 (Electrical service).

Water infrastructures

Water infrastructures ensure water service for drinking water, fire protection, irrigation, cooling (chilled water) as well as sewage. Figure 2.10 shows the general scheme for the drinking, fire protection and irrigation. It includes:

- 8 central plants
- Utility Tunnel for water pipes
- Pipes and related equipment

The central plants are distributed over the Education City. They constitute the main hub for water operation and maintenance. Central plants are supplied from Kahramaa water network.

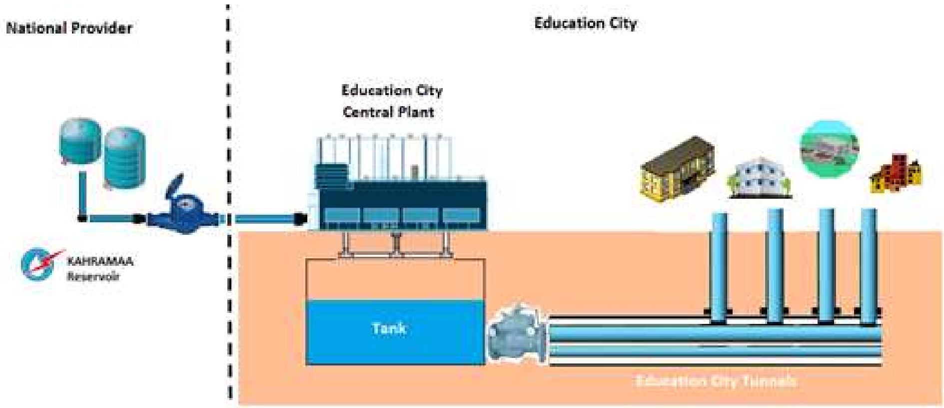
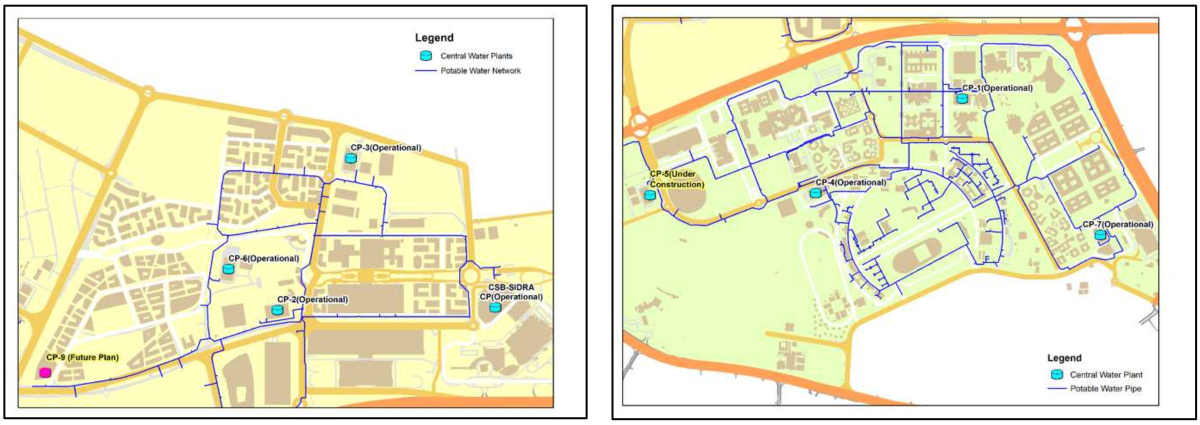


Figure 2.10 Central plants composition and connection

Figure 2.11 shows the distribution of the central plants in the Education City. Central plants CP2, CP3, CP6 and SIDRA CP are located in the North zone, while central plants CP2, CP4, CP5 and CP7 are located in the South zone. Some buildings are directly connected to Kahramaa water networks (QA Schools, Housing Complex and external buildings). CPs of each zone are interconnected via a common water network in the utility tunnel. CPs in the North zone and that in the South zone are not interconnected.

Each central plant includes a tank for water storage as well as the following equipment:

- District cooling plant (Chilled water)
- Utility water pump house for:
    - Potable water
    - Irrigation water
    - Fire protection



North zone South zone

Figure 2.11 Location of the central plants in the Education City

Table 2.3 provides the drinking water storage capacity of the central plants. It varies between 742 m^3 and 13 654 m^3 with an average value of 4 150 m^3. The total capacity storage is equal to 29 075 m^3.

Table 2.4 summarizes the storage capacity of the central plants for irrigation. It varies between 1 768 m^3 and 5 975 m^3 with an average value of 4 700m^3. The total capacity storage is equal to 32 864 m^3, which is about 13% higher than that of the drinking water.

Table 2.3 Drinking water storage capacity (drinking water)

Central Plant	Location	Storage Capacity (cubic meter)
CP1	SOUTH CAMPUS	3232
CP2	NORTH CAMPUS	2164
CP3	NORTH CAMPUS	5259
CP4	SOUTH CAMPUS	3282
CP5	SOUTH CAMPUS	13654
CP6	NORTH CAMPUS	742
CP7	SOUTH CAMPUS	742

Table 2.4 Irrigation storage capacity of the central plants

Central Plant	Location	Storage Capacity (cubic meter)
CP1	SOUTH CAMPUS	1786
CP2	NORTH CAMPUS	4122
CP3	NORTH CAMPUS	5975
CP4	SOUTH CAMPUS	8021
CP5	SOUTH CAMPUS	4448
CP6	NORTH CAMPUS	4144
CP7	SOUTH CAMPUS	4368

Each central plant is managed by a control room using:

- BMS (Building Management System for old buildings).
- SCADA (Supervisory Control and Data Acquisition for new buildings)
- Fire alarm system panel.
- Communication tools (Radio, Phone, Email, etc.)

Electrical system

Figure 2.12 shows the architecture of the electrical system. The Education City is supplied by the National provider Kharamaa through two main stations, who are located in the North and South zones. Electricity is supplied at 220 kV. The main stations transform the electrical power into 66 kV. Then, the electrical power is distributed to 10 EDC (Electrical Distribution Centers), which are located in the South and North zones. EDCs supply substations, which transform the electrical power to 415 V for buildings use.

A central plant transforms the electrical power from 11 kV to 3.3 kV to supply the water chiller and public lighting.

Figure 2.13 and 2.14 show the electrical distribution network in the South and North zones of the campus, respectively. These networks are independent.

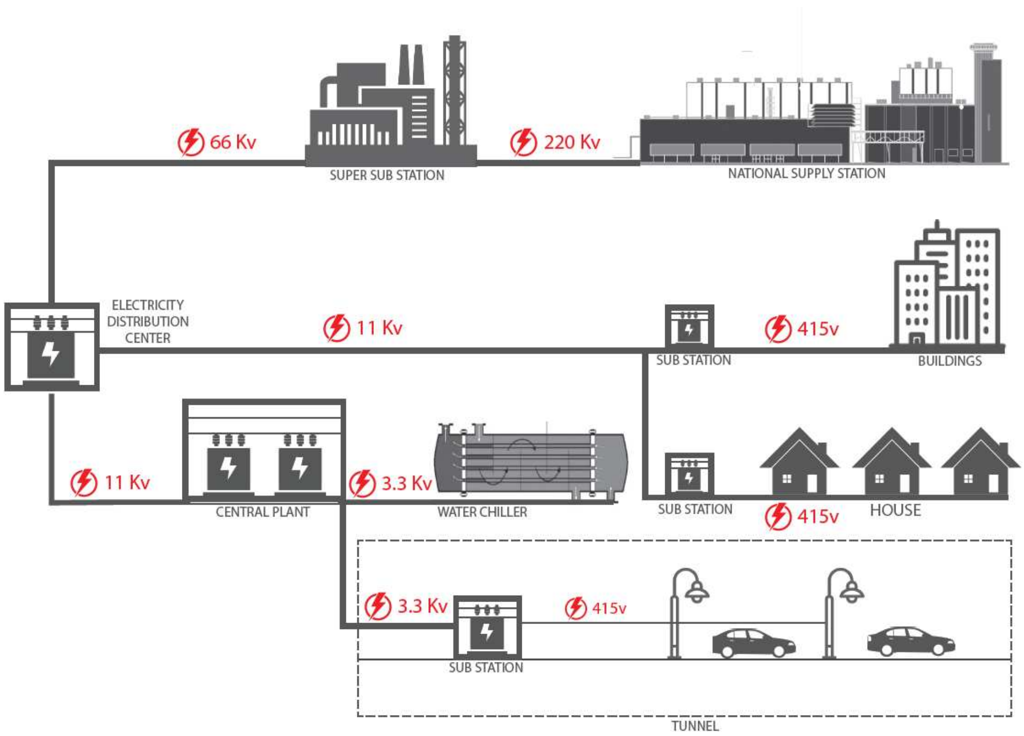


Figure 2.12 Electrical distribution system in the Education City

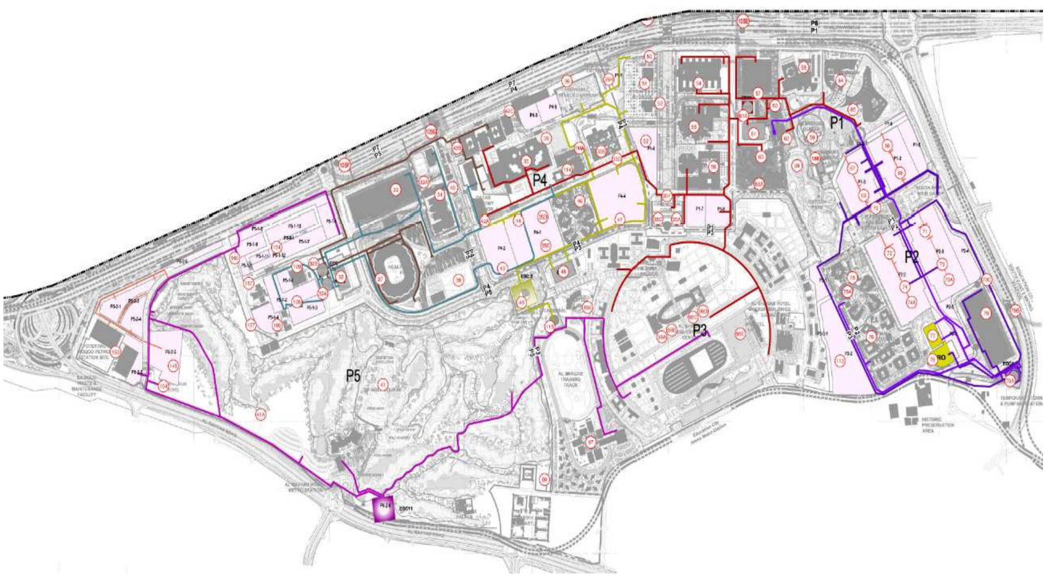


Figure 2.13 Electrical Distribution system in the South Campus

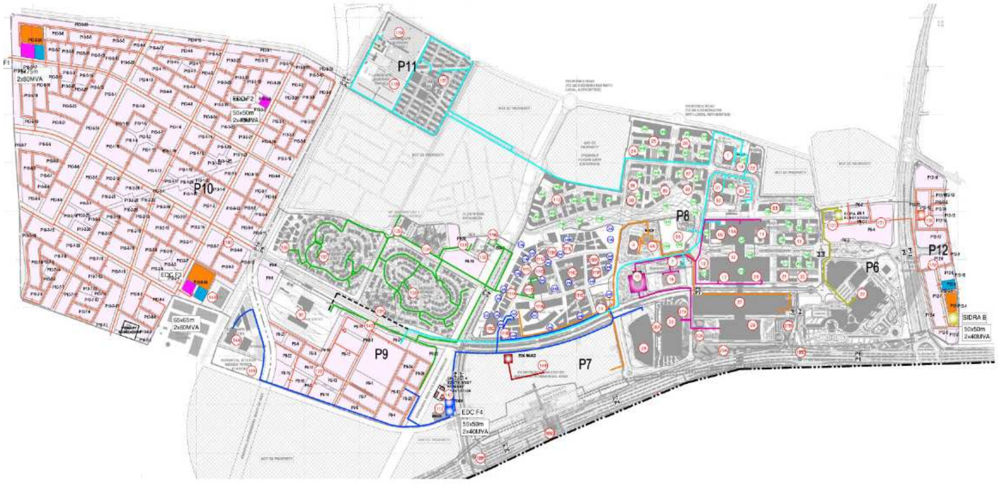


Figure 2.14 Electrical Distribution system in the North Campus

Table 2.5 provides the capacity and date of installation of the EDC (Electrical Distribution Centers). The capacity varies between 40 and 60 Mw. The total capacity is equal to 460 MVA. The first EDC was installed in 2005, while the last one was installed in 2016. 8 EDC were installed between 2009 and 2011.

Table 2.5: Capacity and date of installation of EDC (Electrical Distribution Centers)

Zone	EDC	Capacity (MVA)	Date of installation
North	EDC S	40	May, 2009
	EDC 3	60	Mars, 2010
	EDC 6	60	October, 2009
	EDC 8	40	October, 2016
	EDCSIDRA A	40	Novembeer 2011
South	EDC 1	60	June, 2005
	EDC 2	40	Mars, 2010
	EDC RO	40	May, 2010
	EDC 4	40	Jun, 2010
	EDC 5	40	August, 2010
Total	10	460	

Consumptions data are collected manually by the National provider Kharamaa and the Education City Facility Management team. Up to now, the Education City has not installed Automatic Reading Meters, which allow to follow and analyze data consumption at different time scales.

3.4. Facility Management System

3.4.1. Architecture

The Operation & Maintenance Division is responsible for the management of systems related to the Education City infrastructures such as central plants, utility tunnel, water, energy, buildings, HVAC, logistics and fire protection.

Buildings and facilities are equipped with industrial control systems for Facility Management. These systems are linked to the central plants. Each central plant has a specific control room and each zone has a main control room. However, some buildings are not connected to the central plants and some central plants are not connected to the main central plant.

The Information and Communication infrastructure network has been developed to support communications infrastructure: IT & Telecommunications applications, devices and protocols. It ensures telecommunication services, internet services, and data transport services, including IT communications. The IC infrastructure provides a platform for necessary systems to connect entities within and outside the Education City.

The Facility Management system is composed of 2 parts (Figure 2.15):

- Operational System (OS)
- Industrial Control System (ICS)

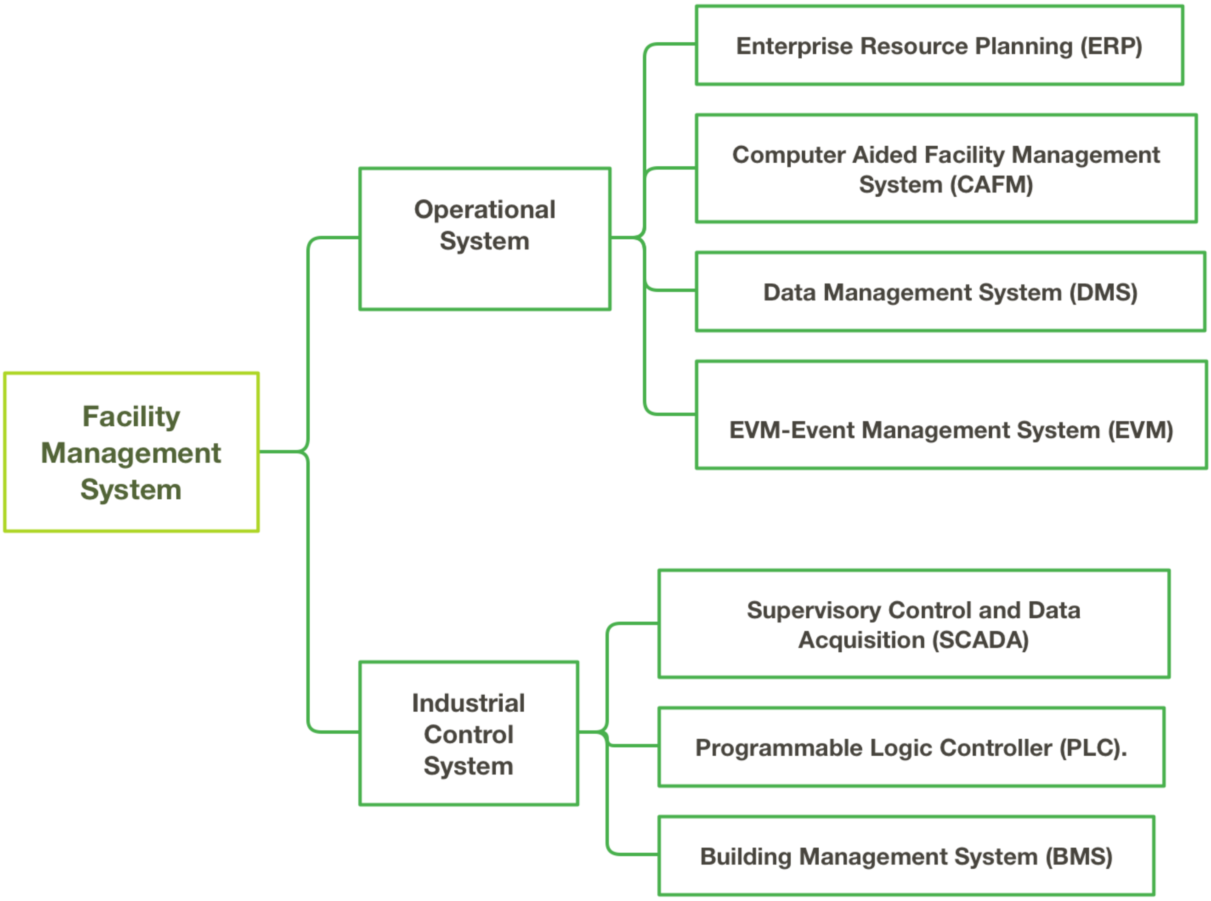


Figure 2.15 Architecture of the Facility Management systyem

3.4.2. Operational system

The Operational System ensures a smooth running of the Education City in terms of efficiency and effectiveness. It provides the capacity to process business transactions and support the city's collaborations and communications. It conducts monitoring of daily activities, such as financial transactions, employee' details and payroll, procurement, data management etc.

The Operational System includes 4 major sub-systems:

1) **Enterprise Resource Planning (ERP):** a core system to manage purchasing, inventory, finance, asset management and human resources.
2) **Computer Aided Facility Management System (CAFM):** a software that streamlines facilities management and maintenance. It conducts space management, real estate planning, project management, building operations, utility and infrastructure operation

and maintenance and preventive maintenance. It leverages facilities data into performance metrics and planning tools to optimize the process of managing facilities

3) **Data Management System (DMS):** it allows to capture organization data into a central repository and make it available to right person at the right time. It uses a (i) SharePoint Portal to publish daily news and to share organization policy, procedure, programs; (ii) an Enterprise Business Intelligence to generate reports and dashboards.
4) **EVM-Event Management System (EVM)**: a system to manage events in terms of schedules and bookings appointments.

3.4.3. Industrial Control System

The Industrial Control System (ICS) uses the following control systems for utility and infrastructures operation and maintenance:

1) **Supervisory Control and Data Acquisition (SCADA):** a control system that uses computers, networked data communications and graphical interfaces for high-level process supervisory management.
2) **A Programmable Logic Controller (PLC):** an industrial computer control system that continuously monitors the state of input devices and makes decisions based upon a custom program to control the state of output devices.
3) **Building Management System (BMS):** a computer-based control system, installed in buildings, to control and monitor building's mechanical and electrical equipment such as, ventilation, lighting, power systems, fire systems and security systems.

3.4.4. Applications

Large diversity of applications is used in the Education City operation and management. Each entity communicates with various authorities and stakeholders using isolated systems, which are generally maintained at the entity level.

Table 2.6 shows applications used by the Education City services. They include a variety of applications for collaboration platform, GIS, buildings management, facility management, financial operations, , inventory, security and risk management. Some of these applications are shared (SharePoint, Business Process Automation), while others are used only by one department /service (finance, ..).

Table 2.7 provides some applications used by some partners of the Education City. They include a variety of applications for students' management, learning, information sharing, collaboration, events booking, reporting and libraries.

Table 2.6 Applications used by the Education City services

Application	End user	Purpose
Portal – SharePoint	All Centers	Collaboration platform.
Business Process Automation	All Centers	A platform to automate business processes.
GIS	Capital Projects Directorate (**CPD**)	QF GIS
Digital Signage	Communications	Centralized solution to manage content for digital display
CAFM – Archibus	Facilities Management	Managing buildings, workplaces, preventive and reactive maintenance
QF ERP - Oracle e-Business Suite - Financials Management	Finance	Payables, receivables, assets and cash management.
Business Continuity	Finance	Develop and maintain business continuity plans.
BPMS - Hyperion Planning	Finance, Human Capital	Budget and resource planning and reporting.
Pelco Camera System	Health, Safety, Security & Environment Directorate (HSSE)	Security Camera, CCTV and Video Surveillance system
Enterprise Project Management (EPM)	IT	Project management.
QF ERP - Oracle e-Business Suite - Procurement Management	Procurement	Purchasing, Inventory and sourcing
Risk Management System	Risk & Compliance	Risk planning and register.

Table 2.7 Some applications used by the Education City partners

Application	**End user**	**Purpose**
FAS – PeopleSoft	Hamad Bin Khalifa University (HBKU)	Financial services
Student Housing Solution	Hamad Bin Khalifa University (HBKU)	Managing Student housing
Learning Management Solution	Hamad Bin Khalifa University (HBKU)	Sharing curriculum, assignments, grading and collaboration.
Banner	Hamad Bin Khalifa University (HBKU)	Student information system.
EMS - Events Management System	Hamad Bin Khalifa University (HBKU)	Events booking.
Lenel Access Control	Health, Safety, Security & Environment Directorate (HSSE)	Access greater security and control
Enterprise Business Intelligence	QF HQ	Integrated reporting and dashboards.
Student Management System	QF Schools	Students information system.
Library Management System	QF Schools	Schools library systems for books and assets.

3.5. Conclusion and recommendations

This chapter included a presentation of the Education City, which is used as a support for this research. This City constitutes an excellent example of sites, which were built with requirements lower than that imposed today regarding sustainablity and efficiency.

The chapter presented (i) the mission, organisation and governance of the Education City, (ii) the master plan including transport infrastructure, buildings and water and electrical systems, and finaly (iii) the Facility Management System.

Governance

The governance model concerns mainly the public part. It is well established with clear roles for the founder (Qatar Foundation for Education, Science and Community Development), the Board of Directors and Executive Office. However, this system does not include independent hosted entities, which use their own strategies and systems for Facility Management. Integration of these entities in the governance system is recommended in order to establish a global strategy for the Education City development and involve all the stakeholders in this development.

Master plan

The Education City was built on a residentital existing area with existing infrastructures. It is compozed of 2 zones (North and South) with indepednt infrastructures and facility management sytems. Each zone includes center plants, EDC (Electrical Distribution Centers) and Utility Tunnem, which are also independent. A global integrated master plan for the Education City is recommended for the facities optimal management.

Infrastructures – utilities

Utilities are organized into 2 groups:

- The water system which uses central plants and the Utility Tunnel for the drinking water, irrigation, sanitation, storm water and chilled water. This system does not include smart metering. Consumptions are collected manually.

- The eclectrical system which uses EDC (Electrical Distribution Centers) and substations for the electrical supply. The electrical grid is not installed in the Utility Tunnel. The electrical system does not include smart metering. Consumptions are collected manually.

Today, some Utility Yunnels in the world host both water and electrical networks. This question could be explored for the Education City.

Automatic Reading Meters should be installed to track water and energy consumptions and dectect upnormal events in the water and electrical systems.

Facility Management System

The Facility Management System includes a large number of systems and applications for the Operational Systems (OS) and Industrial Control System (ICS). An integrated Facility Management System is required for data collection and share, data analysis, decision-making, performance analysis, asset management, operation optimization, safety and optimal investement. This system should be based on the latest technology, that uses smart monitoring, advanced analysis tools and sysyem control. This system will be presented for the water and electrical systems in the following chapters.

Chapter 3: Transformation of the water system

4. Chapter 3: Transformation of the water system

4.1. Introduction

This chapter presents the transformation of the water system of the Education City into a smart water system. It presents first the organization of the water system in particular the central plants, the storage tanks and the utility tunnel. Then, it presents analysis of the current situation of water services: potable water, irrigation, chilled water, storm water, foul water and fire protection. This analysis shows a miss of an integrated system for the management of the water services.

An integrated smart water system is proposed for the optimal management of the water services. This system includes smart monitoring, data analysis and control system.

4.2. Organization of the water system

The water ensures water services for drinking water, fire protection, irrigation, cooling (chilled water) as well as sewage. Figure 3.1 shows the general organization of this system. The water company Kahramaa supplies water to 8 central plants distributed over the campus. Each central plant operates water storage and water treatment and water supply through 4 water networks (drinking, irrigation, fire protection and chilled water) installed in the utility tunnel. The water system of the Education City is composed of two independent systems, which ensure the water service in the North and South Campuses, respectively.

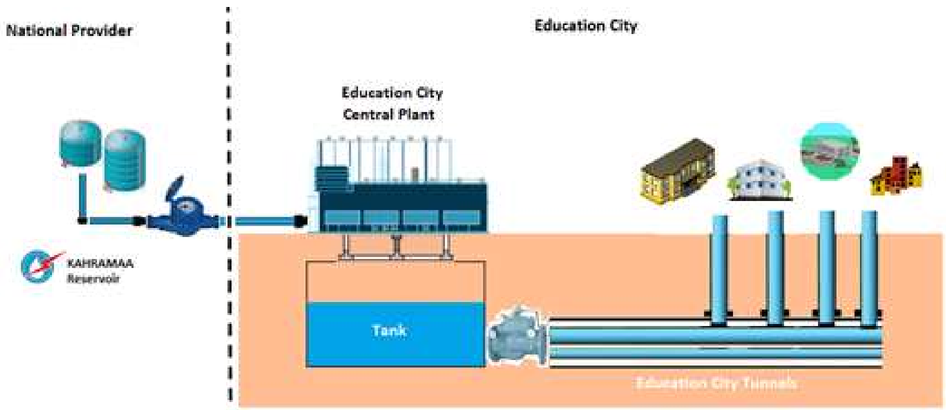


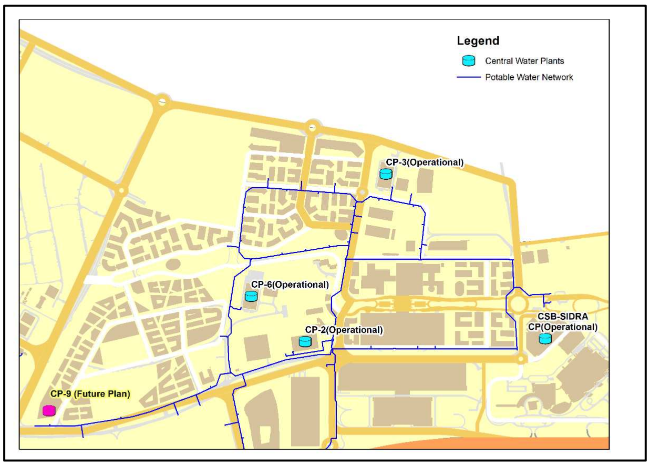
Figure 3.1 Organization of the water system in the Education City

4.3. Central plants

4.3.1. Distribution

The central plants constitute the main hub for the water operation and maintenance. They are supplied directly from Kahramaa water company. Figure 3.2 shows the distribution of the central plants in the Education City. Central plants CP2, CP3, CP6 and SIDRA CP are located in the North Campus, while central plants CP2, CP4, CP5 and CP7 are located in the South Campus. Some buildings are directly connected to Kahramaa water networks (QA Schools, Housing Complex and external buildings). Central plants of each campus are interconnected via a common water network in the utility tunnel.

North Campus



South Campus

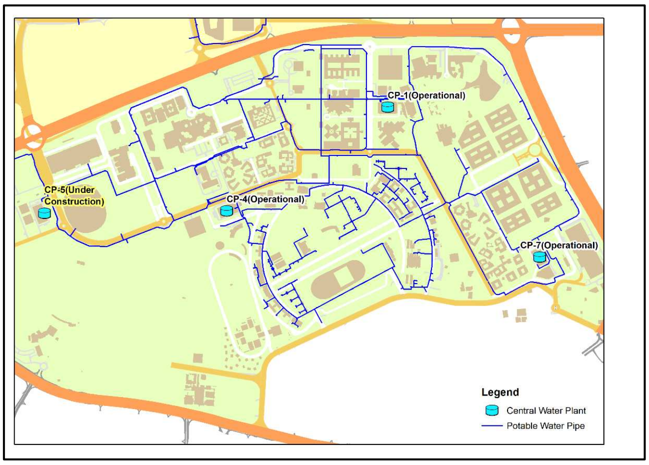


Figure 3.2 Location of the central plants in the Education City

Each central plant includes tanks for water storage and following equipment (Figure 3.3):

- District cooling plant (Chilled water)
- Utility water pump house for:
    - Potable water
    - Irrigation water
    - Chilled water
    - Fire protection

Figure 3.3 Central plants utilities

4.3.2. Management system

Central plants are managed by the Education City-facilities management control room using:

- BMS (Building Management System)
- SCADA (Supervisory Control and Data Acquisition)
- Fire alarm system panel

- Communication tools (Radio, Phone, Email, etc.)

Table 3.1 provides the systems (BMS or SCADA) used in the management of the water systems/ in the Education City. BMS is used in old buildings, while SCADA is used in new buildings.

Table 3.1 Systems used in the management of the water system

Buildings with SCADA	Buildings with BMS
CP-3	All other buildings
CP-6	
CP-7	
CMC	
RDC	
Car park	

4.3.3. Water storage

Central plants are equiped by undergrond tanks to store the water supplied by the water company (raw water tank), the treated water (CT make-up water tank) as well as water for the different usages : fire water tank, irrigation water tank, and potable water tank. Each central plant has two categories of potable water storage:

- Treated water storage and
- Untreated water storage

Figure 3.4 shows the tank storage as well as the pumping equipement.

Table 3.2 provides the drinking water storage capacity of the central plants. It varies between 742 m^3 and 13 654 m^3 with an average value of 4 150 m^3. The total capacity storage is equal to 29 075 m^3.

Table 3.3 summarizes the storage capacity of the central plants for irrigation. It varies between 1 768 m^3 and 5 975 m^3 with an average value of 4 700m^3. The total capacity storage is equal to 32 864 m^3, which is about 13% higher than that of the drinking water.

Table 3.4 provides the list of facilities supplied by each central plant.

Figure 3.4 Central plants tanks storage

Table 3.2 Drinking water storage capacity (drinking water)

Central Plant	Location	Storage Capacity (cubic meter)
CP1	SOUTH CAMPUS	3232
CP2	NORTH CAMPUS	2164
CP3	NORTH CAMPUS	5259
CP4	SOUTH CAMPUS	3282
CP5	SOUTH CAMPUS	13654
CP6	NORTH CAMPUS	742
CP7	SOUTH CAMPUS	742

Table 3.3 Irrigation storage capacity of the central plants

Central Plant	Location	Storage Capacity (cubic meter)
CP1	SOUTH CAMPUS	1786
CP2	NORTH CAMPUS	4122
CP3	NORTH CAMPUS	5975
CP4	SOUTH CAMPUS	8021
CP5	SOUTH CAMPUS	4448
CP6	NORTH CAMPUS	4144
CP7	SOUTH CAMPUS	4368

Table 3.4 facilities supplied by each central plant

Central Plant	Serving Facility
CP1	WCMCQ
	LAS
	TAMU Q
	CMU Q
	New HQ and SSC
	VCU Q
	Ceremonial Entrance
CP4	West Car Park
	Al Shaqab (All buildings)
	Female Student Housing
	AIE
CP7	Male Student Housing
	CMC
	QNL
	GU
	QFIS
	North East Car Park
	Student Centre
CP2	QSTP
	GE
	Truck Marshaling Area
	QNCC-MB, EB
	MV3
CP3	QSTP MV3-9
	MEEZA HQ Office
	QMSC
	QSTP Tech 4
CP6	RDC
	CDC
	QNCC Car Park
	Premier Inn Hotel
CP5	<Under Construction>
CP Sidra	Sidra Medical and Research Center

4.4. Utility tunnel

4.4.1. Organization

The utility tunnel was built through multiple phases during the development of the Education City. Old tunnels have a 3x3 m^2 square section , while recent tunnels have a larger section (4x4 m^2). It is composed of two independents parts (Figure 3.5). The North Utility Tunnel and the South Utility Tunnel (Table 3.5). The length of the North tunnel is equal to 6 840 m including access shafts, stairways, transformer rooms, ventilation, sections drainage channels. The north tunnel connects the central plants CP-2, CP-3 and CP-6 to facilities located in the North Campus.

The length of the South tunnel is equal to 8 888 m. It connects the central plants CP-1, CP-4 and CP-7 to facilities located in the South Campus.

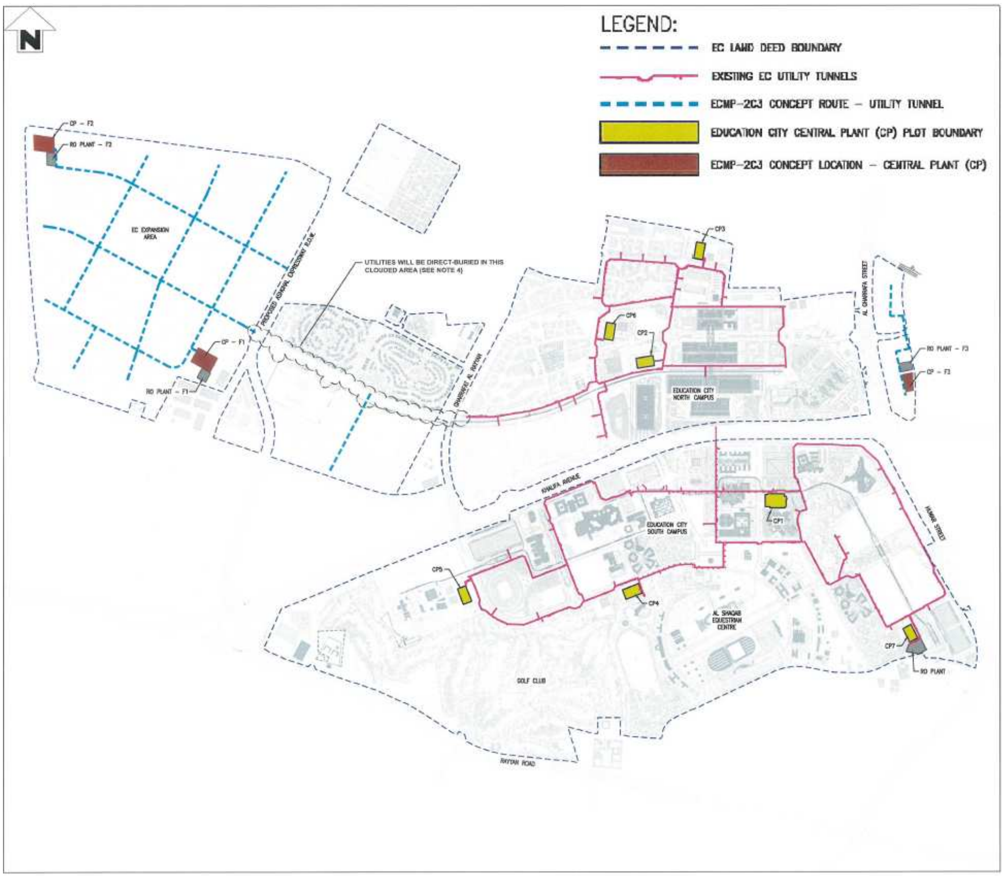


Figure 3.5: Utility Tunnel Layout

Table 3.5 : Main charcterestics of the noth and souuth utility tunnels

Utility Tunnel	Connected central plants	Length (m)
North Utility Tunnel	CP2, CP3, CP6	6 840
South Utility Tunnel	CP1, CP4, CP7	8 888

The utility tunnel management uses the following system:

- RCM (Reliability Centered Maintenance) which is an engineering framework that enables the definition of a complete maintenance regimen
- PPM (Planned Preventive Maintenance)

4.4.2. Hosted utilitites

The utility tunnel hosts the following utilities:

- Irrigation Pipe
- Potable Water Pipe
- Fire Protection Pipe
- Chilled Water Pipe (Supply)
- Chilled Water Pipe (Return)
- Power Cable Tray
- Telecom Cable Tray
- Control BMS/ ELV and Lighting
- Bus Bar
- Fire Horse Reel
- Fire Alarm/ Telecom Tunnel/ Telecom

Table 3.6 provides the characteristics of pipes used in the Education City. Ductile iron is used for utilities, while galvanized iron, ductile iron, PVC, copper and carbon steel are used in buildings.

The diamter of pipes used in fire protection varies between 25 and 250 mm, while the diameter of pipes used in the irrigation and drinking systems varies between 25 and 400 mm.

Table 3.6 : Charcterstics of pipes used in the Education City.

Facility	system	Material	Diameter
Utility tunnel	Fire water line	Ductile Iron	50mm to 250mm
	Irrigation Water Line	Ductile Iron	50mm to 400mm
	Fire / Irrigation	Ductile Iron	50mm to 400mm
	Potable Water Line	Ductile Iron	50mm to 400mm
	Chilled Water Line	Ductile Iron	50mm to 1200mm
Buildiings	**System**	**Material**	**Diameter**
	Fire water line	Galvanized Iron	25mm to 250mm
	Irrigation Water Line	Ductile iron & PVC	25mm to 200mm
	Potable Water Line	Copper & PVC	15mm to 100mm
	Chilled Water Line	Carbon Steel	15mm to 300mm

4.4.3. Safety

They utility tunnel is equiped by 80 mm diameter fire protection pipes, which is connected to the main fire protection system. Fire hose reels and standpipes are provided every 60 m, to comply with Civil Defense and NFPA requirements. Break glasses are available every 30m.

Each tunnel is covered by linear heat detection tapes, which are located above the power cable tray. Each tunnel compartment reports to the nearest central plant. The system does not provide intermediate panels in the event of fire. The tunnel ventilation system purges smoke by increasing the exchange rate up to 10 air changes per hour.

Evacuation points are provided every 100 m. The evacuation section is equal to 2.0m x 2.0m. The covers are double leaf, lockable from both inside and outside with spring loaded latching arrangement; they can be opened from inside the tunnel during an emergency. Access ladders are provided at each evacuation point.

Access to the tunnel is available from the central plant or from access points located every 400 m.

4.5. Drinkibg water system

4.5.1. Organization

The Education City receives water from the water company Kahramaa. It can also receive treated sewage t from the national provider Ashghal. But the later, is not yet activated.

The drinking water system includes three main components:

- Connections to the central plants from Kahramaa networks.
- Water storage in the central plants.
- Distribution network.

Primary connections have been designed to supply the CP storage tanks for a 2 days' need capacity. The existing and planned tie-in network to the central plants is shown in figure 3.6.

Figure 3.7 shows the drinking water network in the North and South campuses.

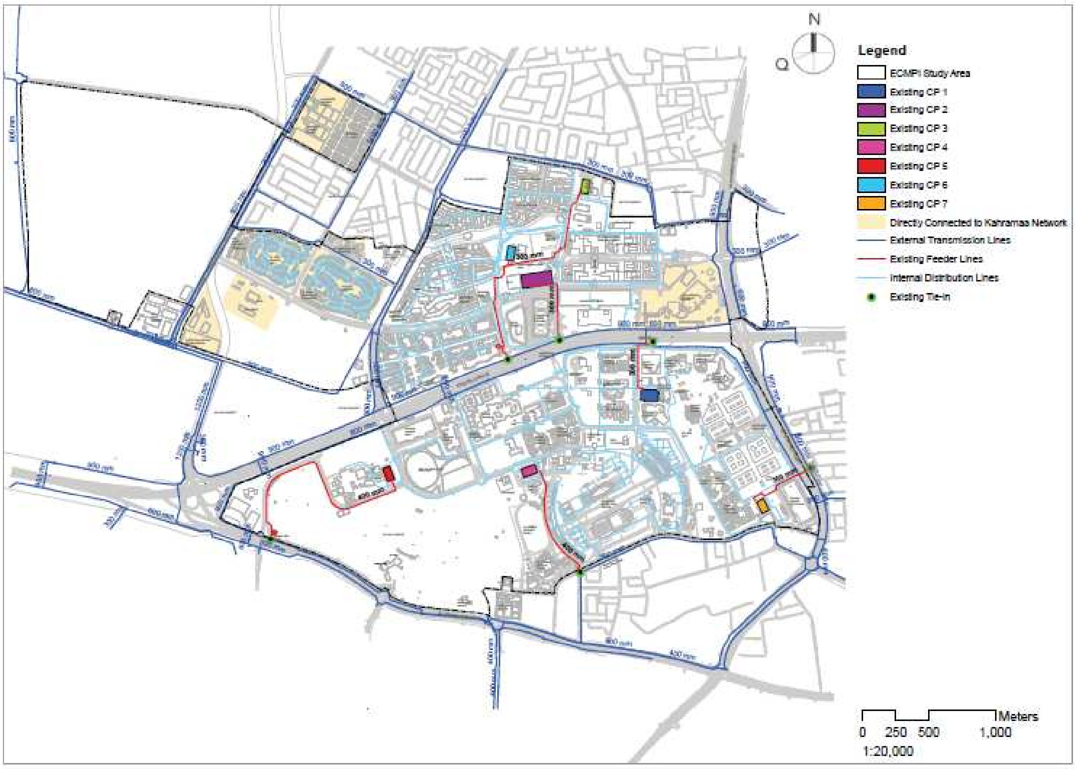


Figure 3.6: Existing and planned tie-in network to the central plants

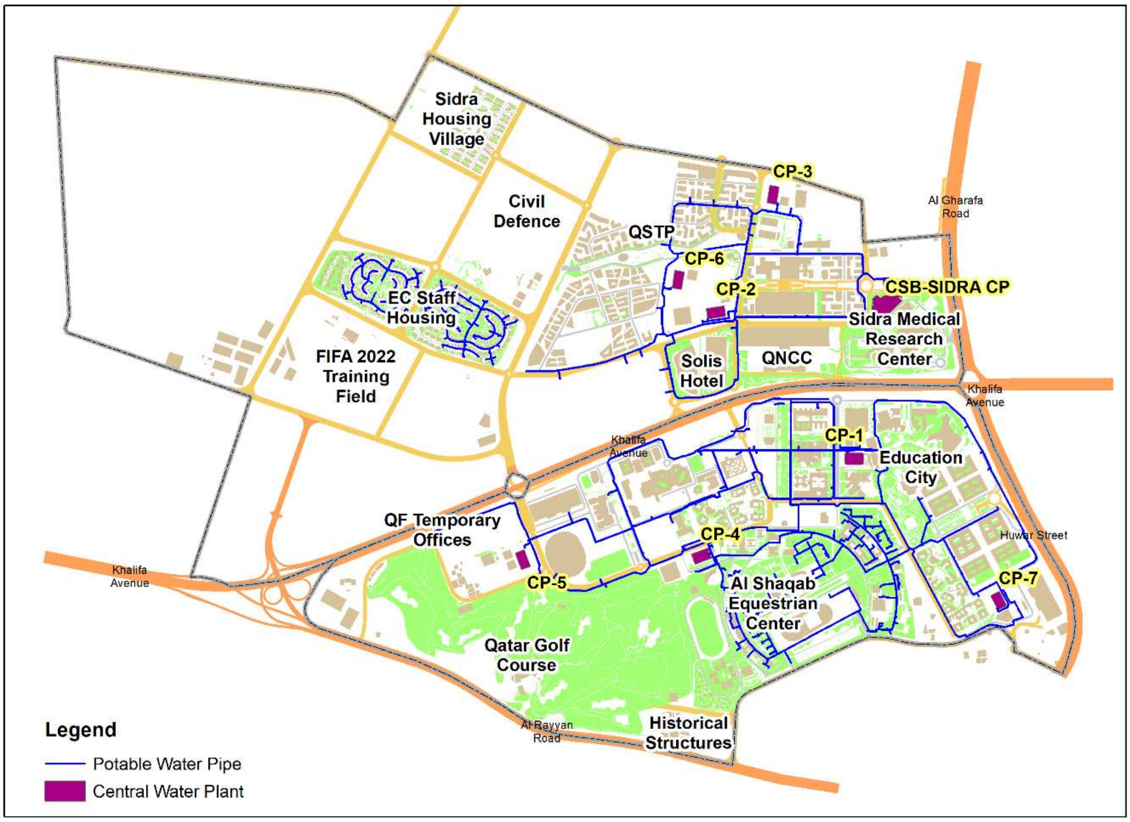


Figure 3.7: ***Potable water network***

4.5.2. Flow meters

Flow meters are installed and maintained by Kahramaa company to measure the water supply of the Education City at the central plants. The Education City installed flow meters at the campus buildings to measure the water consumption. Figure 3.8 shows the flowmeters used in the Education City.

Meter type	Image	Description
Flow meter		Siemens-Magnetic Flow Meter
Flow Meter		ABB-Electromagnetic flow meter
Building Meter		

Figure 3.8 Flow meters used at the Education City

4.6. Irrigation system

4.6.1. Organisation

The total green area of Qatar foundations exceeds 65 hecrtars, distributed over the south and north campuses.

The irrigation network is fed by either direct connection from mainlines located in the utility tunnel or by buildings which have independent water tanks. In some cases, the irrigation network is conneced directly to Kharmaa water system.

The irrigation water distribution is carried as follows:

- The water is discharged to the irrigation mainline then distributed by the irrigation network to the plants through emission devices (Sprinklers, bubblers, drippers, etc).
- The emission devices are designed to supply the water requirements of plants within a specific period of time, which can be scheduled by irrigation controllers or using manual operation.
- Every plant should receive the daily water requirements to ensure a healthy growth according to Qatar QCS requirements.

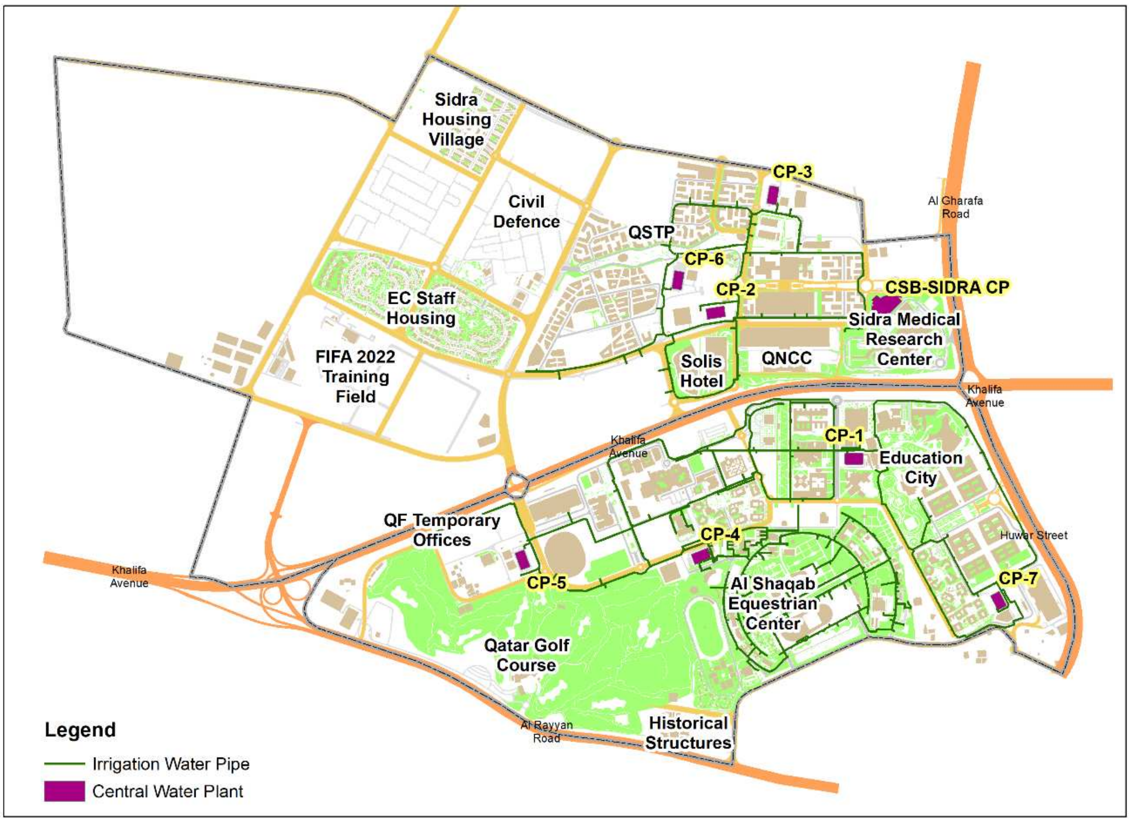


Figure 3.9: Irrigation Water Network

4.6.2. Irrigation systems

The following irrigation systems are used in the Education City (Figure 3.10):

- Irrigation satellite central control system.
- Irrigation stand alone controller.
- Manual irrigation.

The irrigation stand-alone controller works under the followng conditions (Figure 3.11):

- These controllers intended to manage particular zones.
- The watering schedule will be inserted as per the watering requirements of EC.
- The controller will give the signal to the solenoid valve to open and run the water as per the schedule.

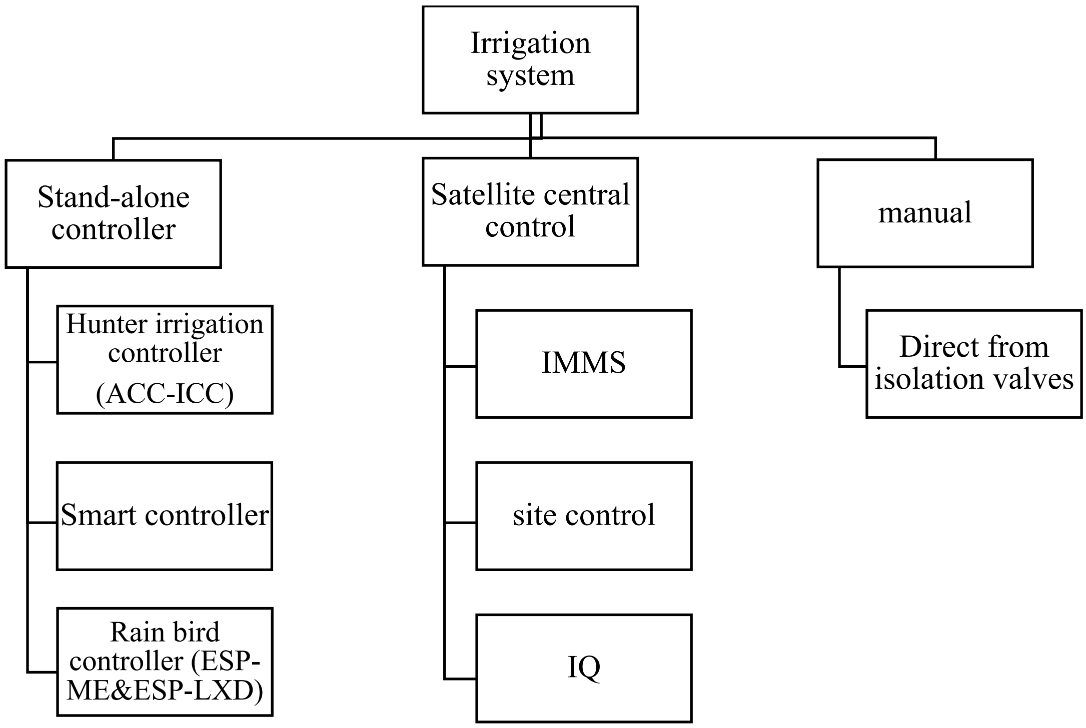


Figure 3.10 Irrigation systems used in the Education City

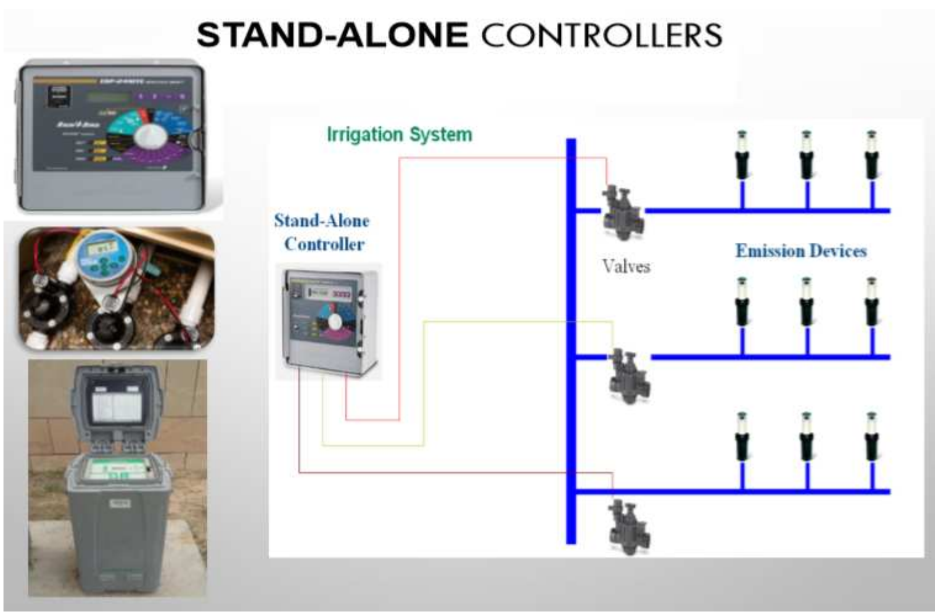


Figure 3.11 Stand-alone controller

The irrigation satellite central control system enables the programming, monitoring, and operation of irrigation systems from a central location, which is designed toon-line control a single site or a set of sites. (Figure 3.12) It sends signals to controllers commanding valves according to the irrigation program. A central control software allows the water manager to set up programming to automatically control satellite controllers or two-wire decoders which operate the irrigation valves. A central control system can monitor and adapt system operation and irrigation run times in response to conditions in the system or surrounding area (weather conditions, pipe breaks, etc.).

The main features of this system are:

- Full two-way communications with ACC.
- Internal communication options to the ACC controller.
- Retrieve actual flow and water usage history.
- Monitor sensors and alarms.
- ET and solar SYNC conservation option.

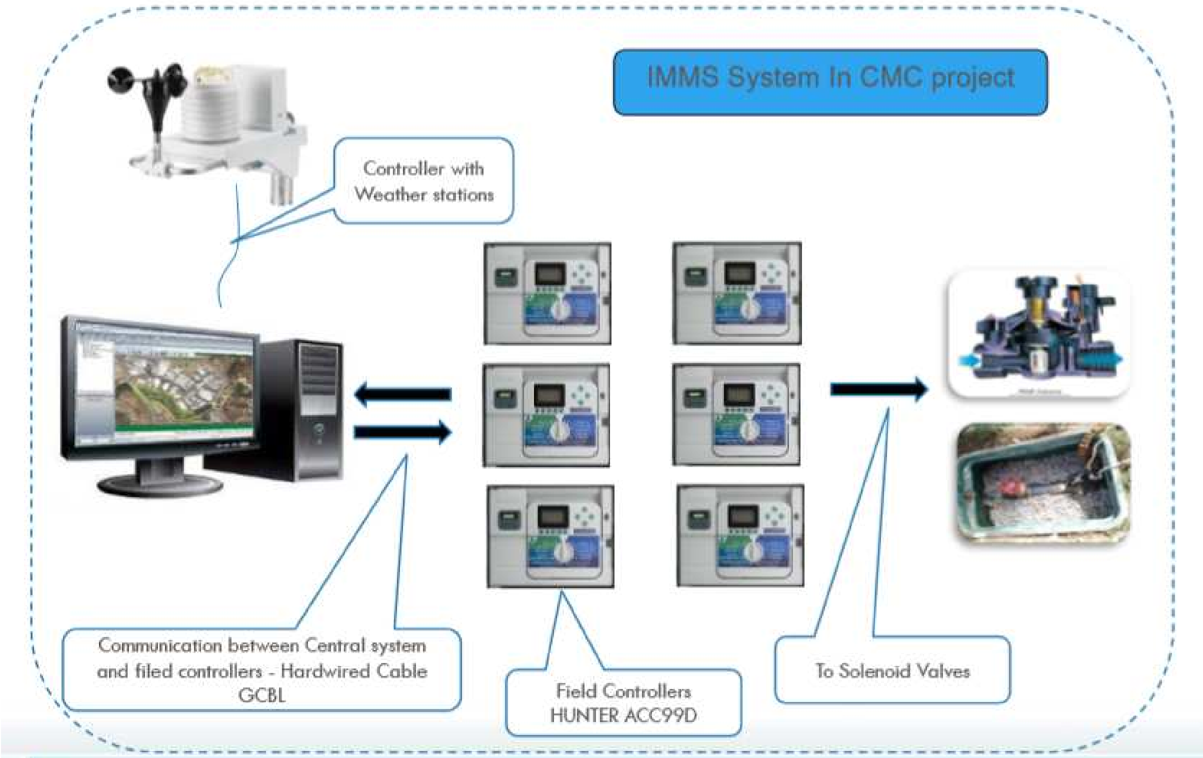


Figure 3.12: Irigation satellite central control system

The manual irrigation system is based on employees, who control manually the irrigation system (valves,…) according to the weather conditions and plants water demand. Figure 3.13 shows the system deployement, while table 3.7 summarizes the water demand of the major plants in the Education City.

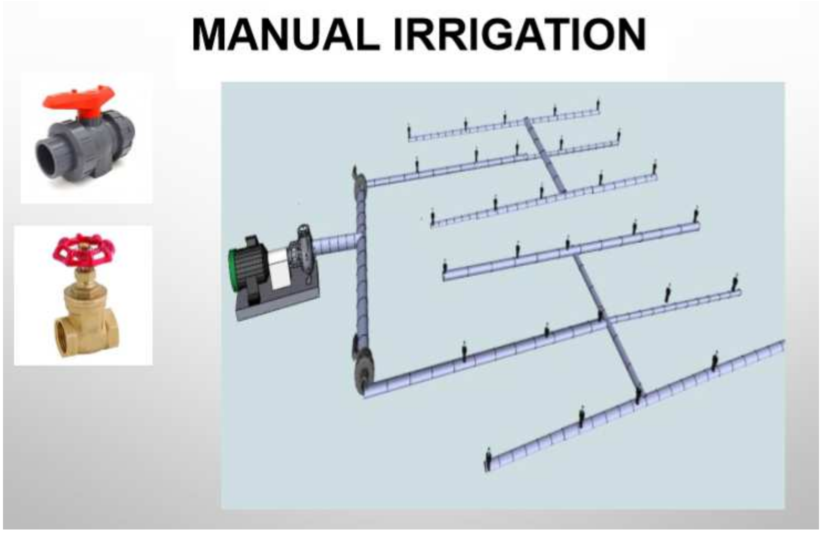


Figure 3.13: EC irrigation manual system

Table 3.7 Plants water demand

Plant Type	Daily Water Requirement	Unit
Palms	80 – 120	ltr/day/palm
Large Trees	50 – 80	ltr/day/tree
Small Tree	30 – 60	ltr/day/tree
Ground Covers	8 – 10	ltr/day/m2
Seasonal plants	8 – 10	ltr/day/m2
Hedges	10 – 12	ltr/day/m length
Large Shrubs	15 – 20	ltr/day/plant
Small Shrubs	8 – 10	ltr/day/plant
Grass	12 – 18	ltr/day/m2
Succulents	8 – 10	ltr/day/plant

-

4.7. Sewage system

4.7.1. Storm water system

The Education City is covered by 2 storm water networks: the North and South strom water networks, which are not interconnected. Figure 3.14 shows the strom water network, while figure 3.15 shows the temporary retention ponds. The collected rain water is discharged into 2 retention ponds, which are located in the north and south campuses.

The North campus storm water network operates under gravity. The water runoff is connected to the manholes via pipes of different sizes (figure 3.16) through road gullies and finally the water is discharged to the infiltration ponds. The water network system in the south campus work also under gravity with additionalli lift pumping stations to transport storm water to another pond. Table 3.8 summarizes the main characterestics of the strom water nerwork.

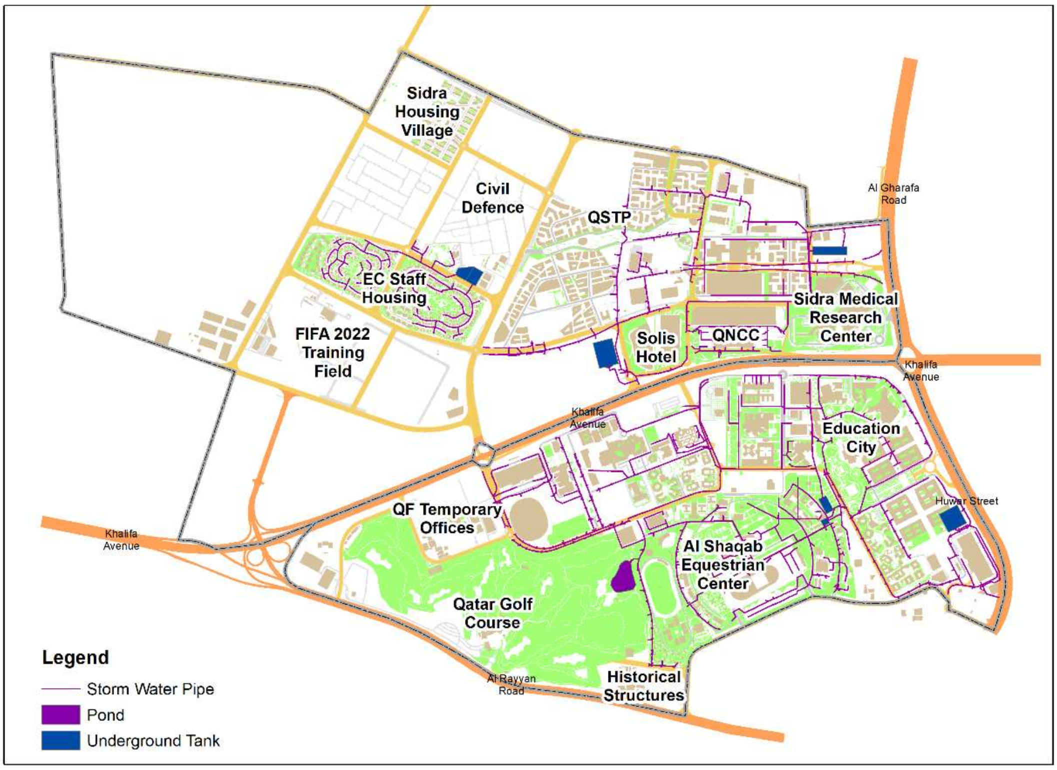


Figure 3.14: Storm Water Network

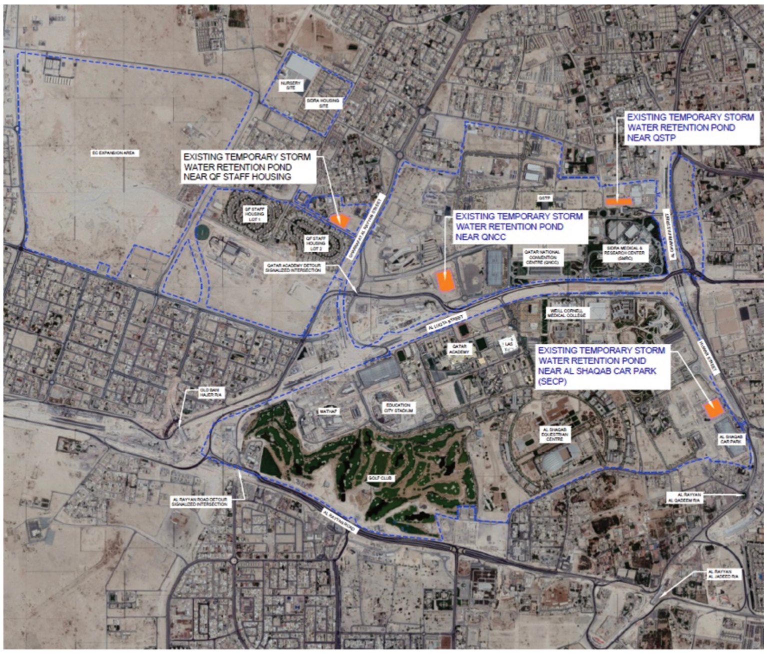


Figure 3.15: Retention water ponds

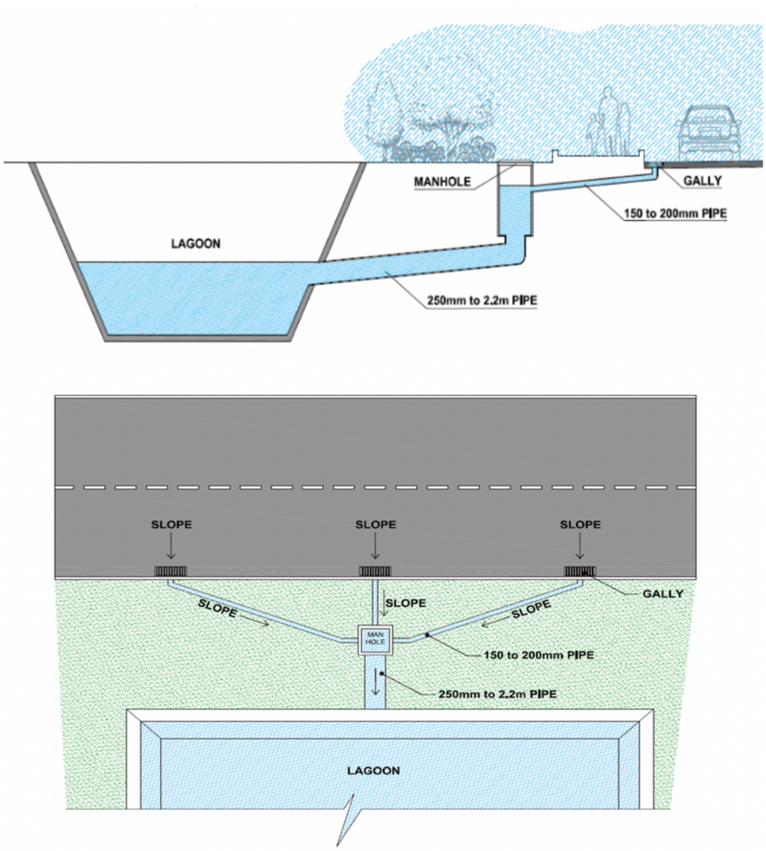


Figure 3.16 Storm water system

Table 3.8: Characterestics of the storm water network.

Item	Data
Depth of storm water utility	More than 1.2 m
Size of the pipes	150 to 2200 mm
Type of pipes	V.C.P vitrified clay pipes
Gullies	45cm X 45cm

4.7.2. Foul water system

The foul water system is split between the North Campus and South Campuses. Foul flows generated from the North Campus is discharged in the Gharrafa Trunk Sewer, and then transported to the South Campus. Gharrafa Trunk Sewer discharges to an existing Pumping Station 34 (PS 34) of ASHGHAL, which is located outside the Education City. PS 34 has been recently upgraded to a capacity of 1400 l/s. The total foul flow from the EC is equal to 220 l/s (19 008 m3/day).

4.8. Chilled Water

Figure 3.17 shows the chilled water system in the Education City. Chilled water is provided to the North Campus from the central plants CP2, CP3 and CP6, whilst the South Campus is served by the central plants CP1, CP4, CP5 and CP7.

The chilled water networks for the South and North campuses are connected through the utilities tunnel, to create an integrated network across the Education City. Pre-insulated carbon steel pipes are used in the network. The maximus pressure in the network is equal to 6 bars.

Buildings are connected to the chilled water network using substations including energy transfer stations, which are equiped to measure energy consumption and operate process control.

Table 3.9 provides the energy capacity of the chilled water plants in the Central Plants. The capacity of the central plants in the North campus is equal to 91 tons (740.8 MWh), while that in the South campus is equal to 54 tons (439.6 MWh).

Table 3.9 : Energy capacity of the chilled water central pants

	Central Plant	CP Capacity (tons)
North Campus	**CP-2**	11
	CP-6	40
	CP-3*	40
South Campus	**CP-1**	11
	CP-4	11
	CP7	32

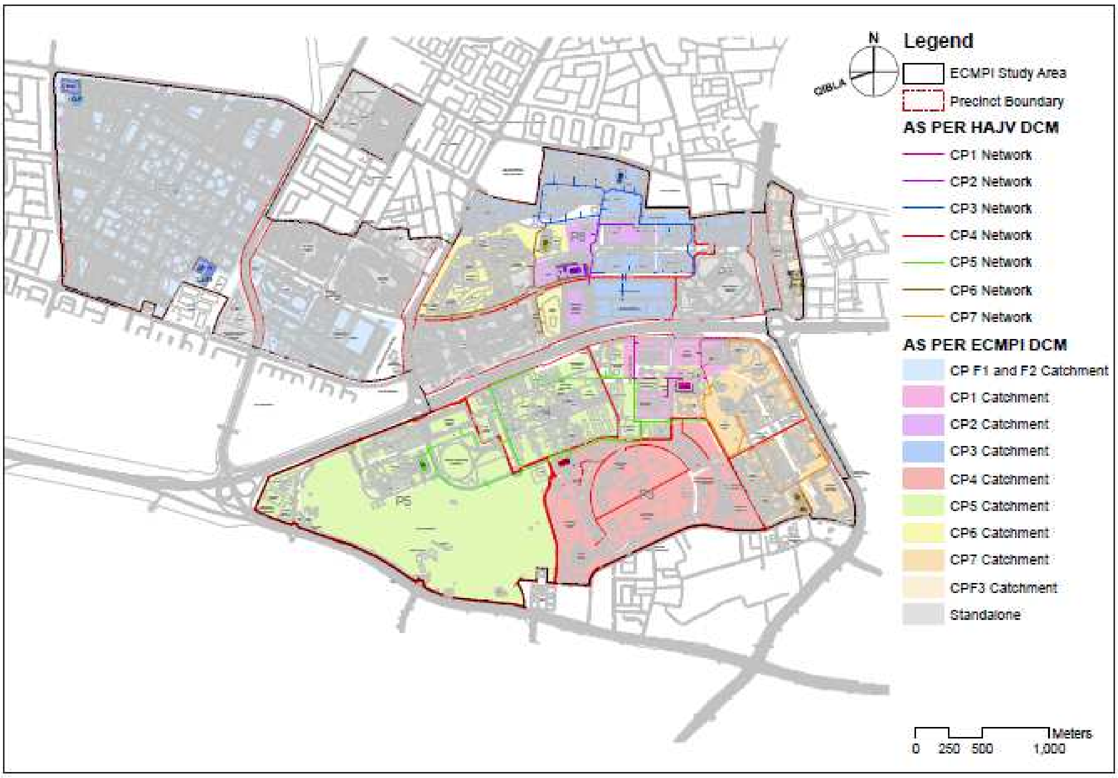


Figure 3.17: Chilled water system

4.9. Fire protection system

4.9.1. Organisation of the fire protection system

The fire protection system is served by the central plants and associated networks (Figure 3.18). The firefighting catchment areas are predominantly based on central plants (CP) locations. Flexibility is provided via primary connections between catchment areas.

The Education City fire system includes:

- Facilities with fire water pumps and fire water tanks.
- Facilities with fire water pumps and without fire water tank.
- Facilities connected directly with main fire water network (without fire water pumps &without Fire water tanks).

In case of a central plant failure, any facility within its service area will receive fire-fighting water from the nearest central plant in case of a fire event. In addition, central plants will supply each other in case of failure.

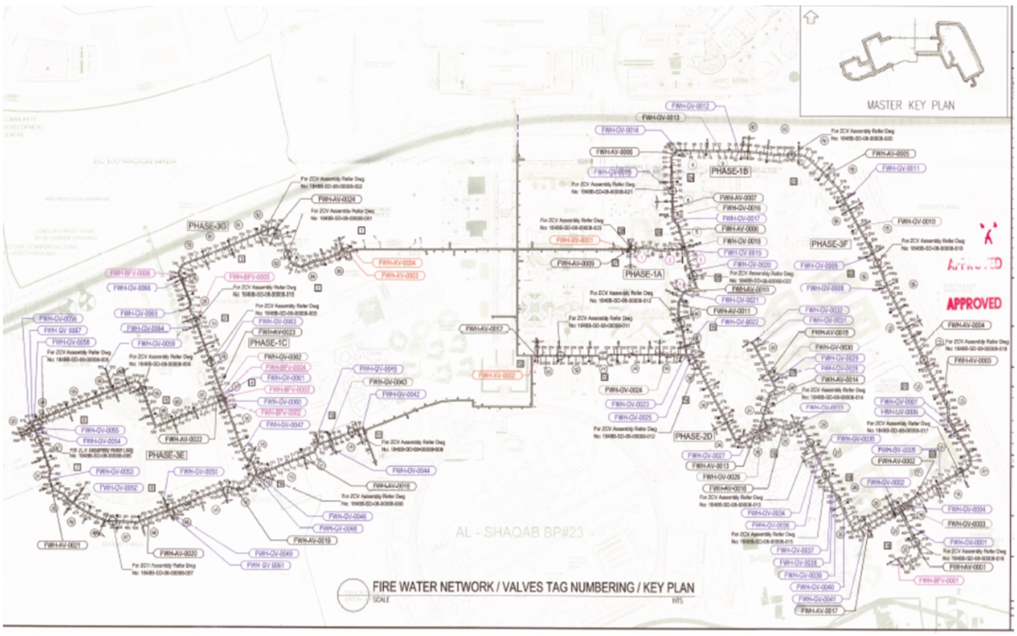


Figure 3.18: Fire water network

Tables 3.10 and 3.11summarize the water storage capacity and pressure. The total storage capacity in the North campus is equal to 2 122 m^3 (2.07 hours fire water demand), while that of the South Campus is equal to 3 000 m^3 (2.2 Hours fire water demand).

Table 3.10 Fire water system requirements (Design)

Parameter	Design Criteria
Storage Capacity	2 hours
Minimum Pressure	5.0 bars
Maximum System Pressure	12.0 bars

Table 3.11 Cuurent fire water storage capacity of the central plants

Campus	Central Plant	Storage Capacity (m^3)	2-Hours Fire Demand (m^3)	Remarks
NORTH	**CP2**	750	681	Current storage capacity is sufficient for 2-hours fire demand
	CP3	622	681	Current storage capacity is sufficient for y 1.8-hours fire demand. Supply from adjacent CP can be used.
	CP6	750	681	Current storage capacity is sufficient for 2-hours fire demand
SOUTH	**CP1**	750	681	Current storage capacity is sufficient for 2-hours fire demand
	CP4	750	681	Current storage capacity is sufficient for 2-hours fire demand
	CP5	750	681	Current storage capacity is sufficient for 2-hours fire demand
	CP7	750	681	Current storage capacity is sufficient for 2-hours fire demand

4.9.2. Fire hydrant

Hydrants are placed along roads or outside buildings to fight external fire. The fire system maintains a pressure ranging beween 5 and 12 bars. Figure 3.19 shows the distribution of the 287 fire hydrants. They are spaced every 100 meters and 45m from buildings.

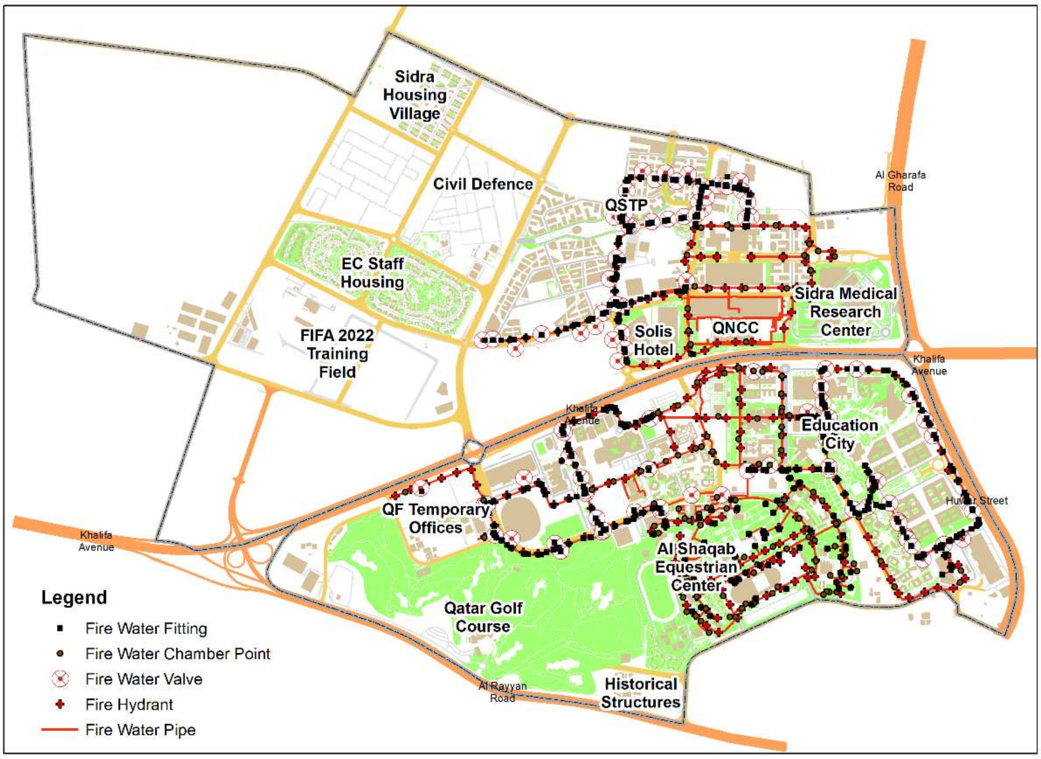


Figure 3.18: Fire hydrants in the Education City

4.10. Transformation of the water system into a smart system

4.10.1. Integrated smart solution

The transformation of the current water system into a smart water system requires an integrated approach that based on the construction of a unique platform, which ensures data collection and storage, data analysis, data visualization and operation control.

The integrated smart water system presented in this section is based on research and achievements of SunRise project (Abour Rjeily, 2017, Farah, 2017, Abbas 2017, Saab 2018) as well as the outcome of the European project SmartWater4Europe[5].

[5] https://sw4eu.com/

The architecture of the integrated smart water solution is presented in Figure 3.19. It works as follows.

(i) A platform coordinates all the operations related to the smart management of the water system. This platform is called the Education City Smart Platform (ECSP).

(ii) The system includes an information system, which stores all the data related to the water system, including:
- The assets data of the water infrastructures, which are collected using GIS and eventually BIM. All the components and attributes are integrated in the same system and could be visualized in GIS environment
- Data collected by the sensors, which cover concern the system security and optimal operation, such as water flow, water pressure, temperature, water quality, water level,…
- Maintenance and operation data collected from the maintenance operation.
- Other data such as the weather,…

(iii) Data analysis is conducted using engineering software such as those used in leak detection, contamination detection, flood control, water availability, operating parameters control (pressure, flow, temperature,…). Artificial Intelligence is also used for data analysis. It allows to learn from historical data, to identify the operating trends and interaction as well as abnormal events and actions to be taken in case of an abnormal event. It allows also the optimal management of the water system.

(iv) Data visualization is conducted using GIS software as well as specific software to visualize the operating conditions, incidents, maintenance,

(v) The results of data analysis are turned into operational data (security and optimization) and transmitted to the water system through command equipment such as valves, switches, motors,…

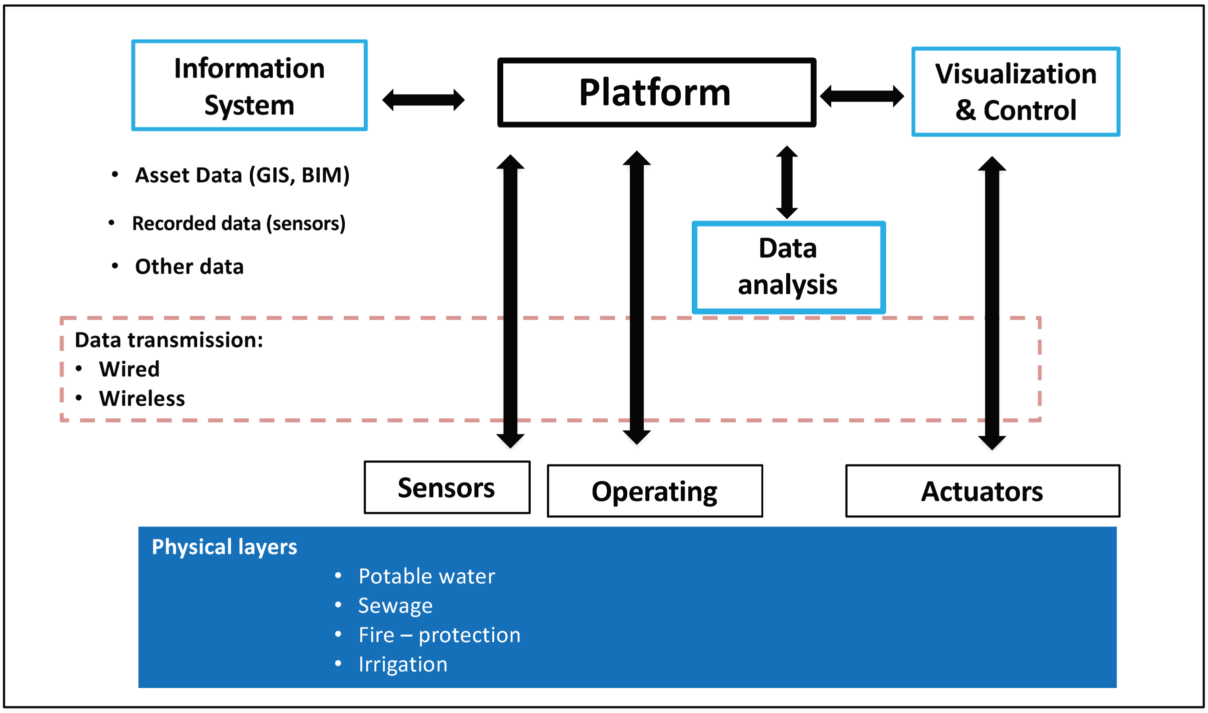


Figure 3.19: Architecture of the smart water solution

4.10.2. Data transmission

Data transmission from sensors to the Education City Platform is conducted using LoRa data transmission system. This system works as follows:

- LoRa transceivers are embedded into the water smart sensors.
- LoRa transceivers transmit data from sensors to Gateways; data transmission could be conducted over near and far distances.
- Gateways transmit data to the server using Wi-Fi, Ethernet or cellular connections.

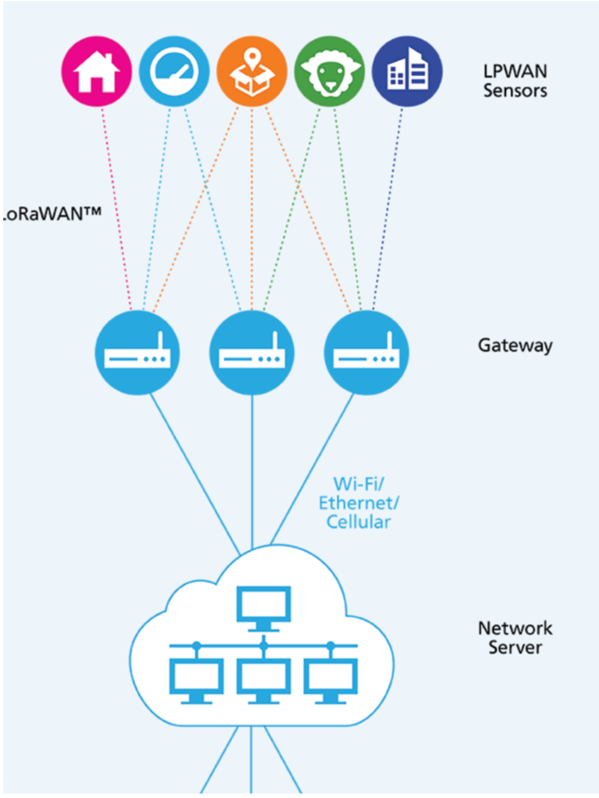


Figure 3.20 LoRa data transmission system[6]

4.10.3. Smart drinking water

The smart drinking water system aims at:

- Detection of water leak
- Early detection of water contamination
- Community information and awareness

A) Water leak Detection

For water leak detection, the water system is monitored using Automatic Meter Readings (AMR) which measure water consumption and then transmit readings to a data collector and then to a the Education City Smart Platform. AMR are installed at the following locations (Figure 3.21):

[6] https://www.semtech.com/lora

- Water supply from Kahramaa
- Water tank outlet
- Water supply of buildings and other facilitates.

Thanks to this installation, the manager of the potable water can tack at one-hour interval the water supply from Kharamaa company, water supply from the tank of the central plant and the water supply of all the buildings in the campus.

A level water sensor is installed in the water tank in order to track the water level in the tank and determine the filling rate.

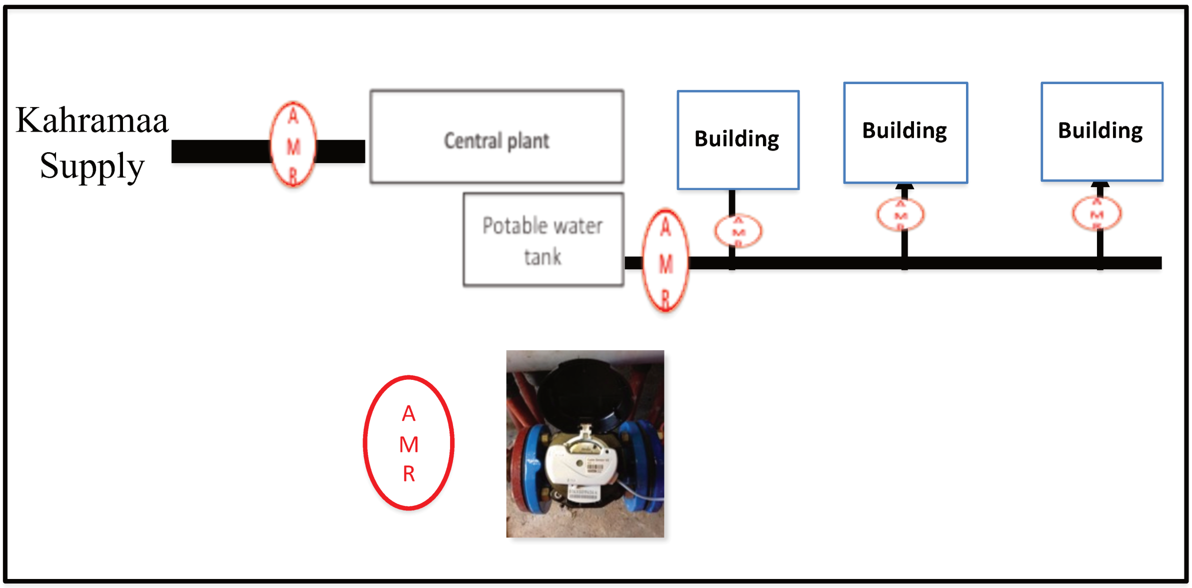


Figure 3.21 Drinking water monitoring for leak detection

The AMR at the supply section will allow to control Kahramaa billings.

Leak in the water tank could be controlled from the AMR of Kahramaa supply, AMR at the tank outlet and the water level sensor.

Leak in the water network could be determined using the DMA method (District Metering Areas), which consists in checking the balance between the water supply (tank outlet AMR) and the totality of the water consumption in buildings (sum of AMR of buildings in the DMA).

Leak in buildings could be determined using the Artificial Intelligence (AI). For each building, the consumption profile is established from historical data. Real time readings from AMR are then compared to consumption profile. In case of a gap with between the readings and the consumption profile, a leak event is created with a severity degree related to the amount of the gap between the profile and the readings.

B) Water quality control

The water quality is controlled using S::CAN micro station for drinking water installed at the outlet section of the water tank (Figure 3.22). This station records the following water quality parameters: UV, Turbidity, TOC, DOC, Temperature, Color, pH, Conductivity, Temperature and Chlorine. Data are recorded at 2 minutes interval and transmitted to the Education City Platform.

Figure 3.22 S::CAN Micro::station for drinking water

Data analysis is based on the deviation of readings from the parameters base-line. Figure 3.22 shows events recorded by Saab (2018) at the Campus of Lille University. The deviation from the base-line indicates events related to water quality change. For the determination of the contamination origin, Saab (2018) proposed to use a combination of data recorded by the

Chlorine and Turbidity sensors. This method will be implemented in the Education City Smart Water System.

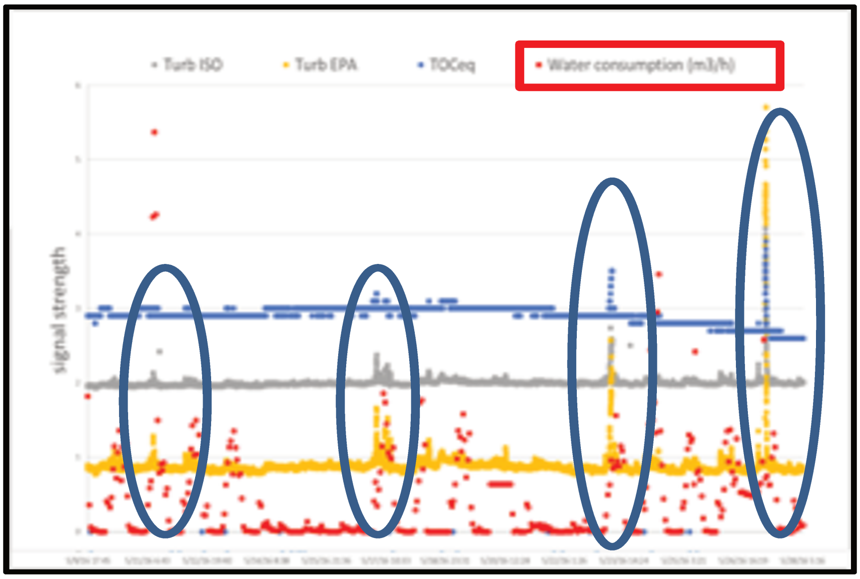


Figure 3.22 Water quality control using S::CAN (Saab, 2018).

C) Users information and awareness

The Education City platform uses a friendly interface to visualize the water consumption in the campus as well as events related to water leak and quality. Colors are used to illustrate the level of consumption regarding standard consumptions. Red color is used for high consumption, green color is used for buildings with low consumption.

4.10.4. Irrigation system

The smart irrigation drinking system aims at:

- Detection of water leak
- Optimization of the irrigation process.

A) Leak detection

Figure 3.23 shows the monitoring system of the irrigation system. It is similar to that of the drinking water system in replacing buildings by irrigation stations. Leak detection is conducted using methods presented in the drinking water section.

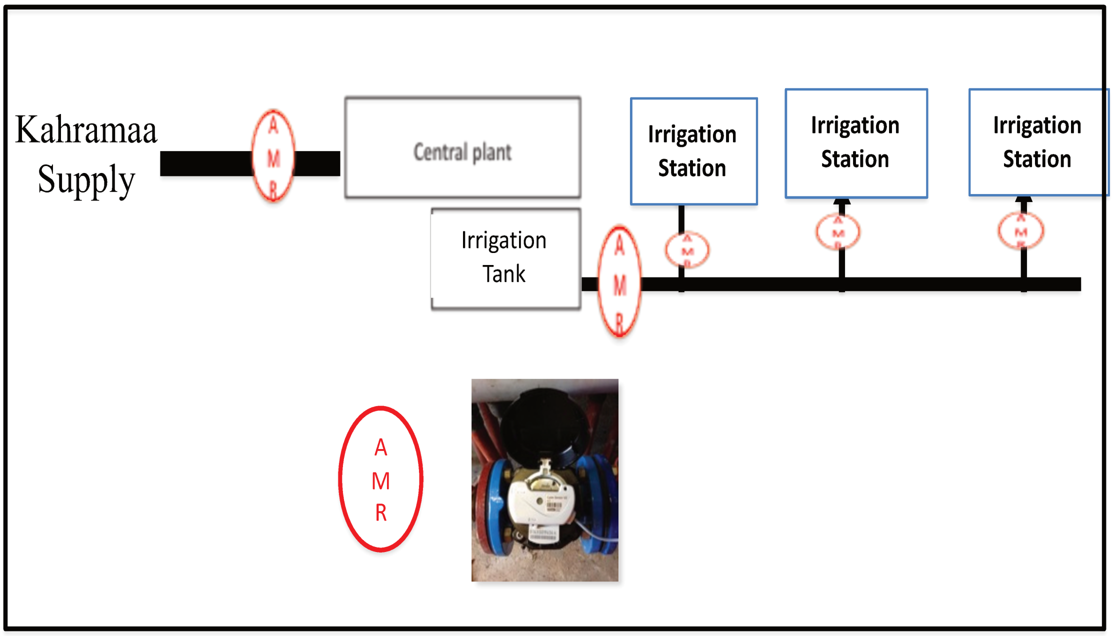


Figure 3.23 Irrigation system monitoring for leak detection

B) Irrigation optimization

The smart irrigation is based on the optimal control of the irrigation system to ensure the required soil moisture in root zone according to the type of the plant. Soil moisture sensors are used to measure soil moisture content and to transmit readings to water controllers. Two soil moisture sensor-based systems available:

- Suspended cycle irrigation systems, which use the traditional timer controllers, with watering schedules, start times and duration; the system stops the next scheduled irrigation when there is enough moisture in the soil.
- Water on demand irrigation system, which initiates irrigation when the soil moisture level fails to meet the moisture requirements.

4.10.5. Fire water system

The smart fire water system aims at:

- Detection of water leak
- Hydrants pressure control

A) Leak detection

Figure 3.24 shows the monitoring system of the fire water system. It is similar to that of the drinking water system in replacing buildings by hydrants. Leak detection is conducted using methods presented in the drinking water section.

B) Hydrants pressure control

Pressure sensors are added at the hydrant to control the water pressure according to the regulation requirements. This control could be done at short time intervals (hourly, daily, ..).

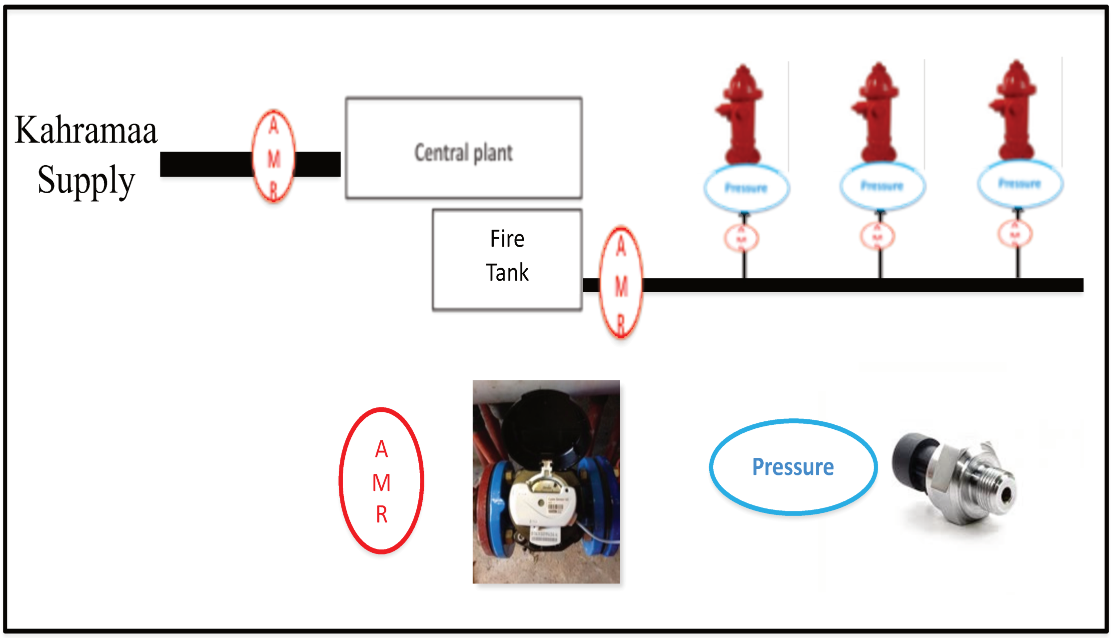


Figure 3.24 Fire water system monitoring

4.10.6. Storm water system

The storm water system aims at preventing flood risk.

The monitoring system includes (Figure3.25):

- Weather station to measure rainfall intensity

- Water level in critical manholes, which should be determined according to historical flood events or numerical modelling.
- Water level in the lagoon
- Water flow meters in main storm water pipes.

Flood prevention is based on the water level in both the lagoon and critical manholes. Application of the Artificial Intelligence on historical data (rainfall intensity, water level in manholes and lagoon, water velocity) allows to determine for each rainfall scenario the expected water level in the lagoon and critical manholes and then to determine the flood risk level. According to the risk level, predetermined actions are carried out such as sending alert messages, water flow control, use of temporary retention basin,…

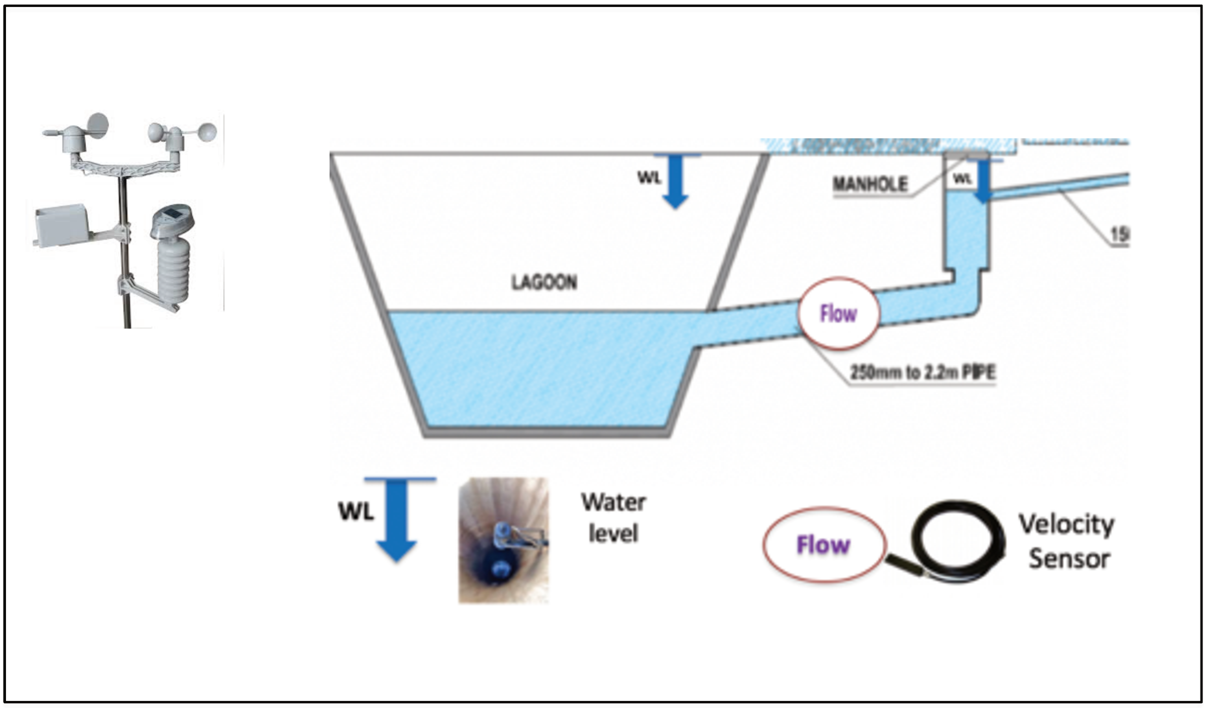


Figure 3.25 Storm water system monitoring

4.11. Conclusion

This chapter included a presentation of the water system of the Education City. This system ensures water services such as potable water, irrigation, chilled water, storm water, foul water and fire protection. The system is deployed independently in the North and South campuses. It is organized in 3 parts:

- The Central Plants, which ensure water storage and supply for the different services
- The utility tunnel, which hosts the main pipe to supply the service nodes (buildings, hydrants, irrigation station,..).
- The services nodes, which ensure the different water services/

The water system was built according to the requirements of construction time. It suffers from fragmented management, lack of monitoring, lack of cooperation between central plants and campuses. The monitoring system does not allow rapid detection of leak or fault operating.

In order to improve the water service management, a smart water system is proposed with:

- Integrated platform for the management of water services
- Integrated information system, which includes asset data as well as operating data
- Data analysis tools, including engineering and Artificial Intelligence tools
- Data visualization and system control

For each water service, the chapter describes the challenges the water system, smart monitoring, data analysis as well as their use in system control. Thanks to the smart system, water leak and contamination could be rapidly detected, flood risk impact is reduced, the control of the fire water devices is improved, and the irrigation system is optimized.

The proposed smart water system could be easily extended to incorporate smart maintenance.

4.12. References

- ABOU RJEILY Yves (2016) “Management and Sustainability of Urban Drainage Systems within Smart Cities” Université de Lille, 2016.
- FARAH Elias (2016) « Detection of water leakage using innovative smart water system – Application to SunRise Smart City Demonstrator» Université de Lille, 2016
- SAAB Christine (2018)“Smart system for water quality control: feedback from large-scale experimentation”, Université de Lille, 2018.

Chapter 4: Transformation of the electrical system

5. Chapter 4: Transformation of the electrical system

5.1. Introduction

This chapter presents the transformation of the electrical system of the Education City into a smart grid. It presents analysis of the organization of this sector in particular the 11 kV grid.

This analysis shows that the electrical system should be upgraded using the Smart Grid technology to provide an integrated system for management of the totality of the grid of the Education City that improves the efficiency and security of the electrical grid and facilitates the integration of renewable sources. The smart grid architecture is presented in this chapter. Information provided in this chapter are based on the Master Plan dated May 2015.

5.2. Organization of the electrical system

Figure 4.1 shows the architecture of the electrical system of the Education City. The National provider Kharamaa supplies the Education City two main super-stations, who are located in the North and South campuses. Electricity is supplied at 220 kV. The capacity of each super-station is equal to 600 MVA. In order to ensure the resilience of the electrical supply, the firm capacity of each super-station is limited to 400 MVA.

The North and South Campus HV network are programmed to be electrically independent. However, this full independence has not been achieved yet due to a disparity between the planned future capacity to be available at the South Campus and the currently required load. The Super substation located in the North Campus (EDCS) still reinforces the South Campus load.

The super- station transforms the electrical power from 220 kV to 66 kV to feed the Electrical Distribution Centers (ECDs), which then transform the electrical power to 11 kV feed the substations. The later transform the electrical power into 415 V to supply buildings and facilities of the Education City.

A central plant transforms the electrical power from 11 kV to 3.3 kV to supply both the water chiller and public lighting.

Figure 4.2 and 4.3 show the electrical distribution network in the South and North campuses, respectively. They are not installed in the utility tunnels.

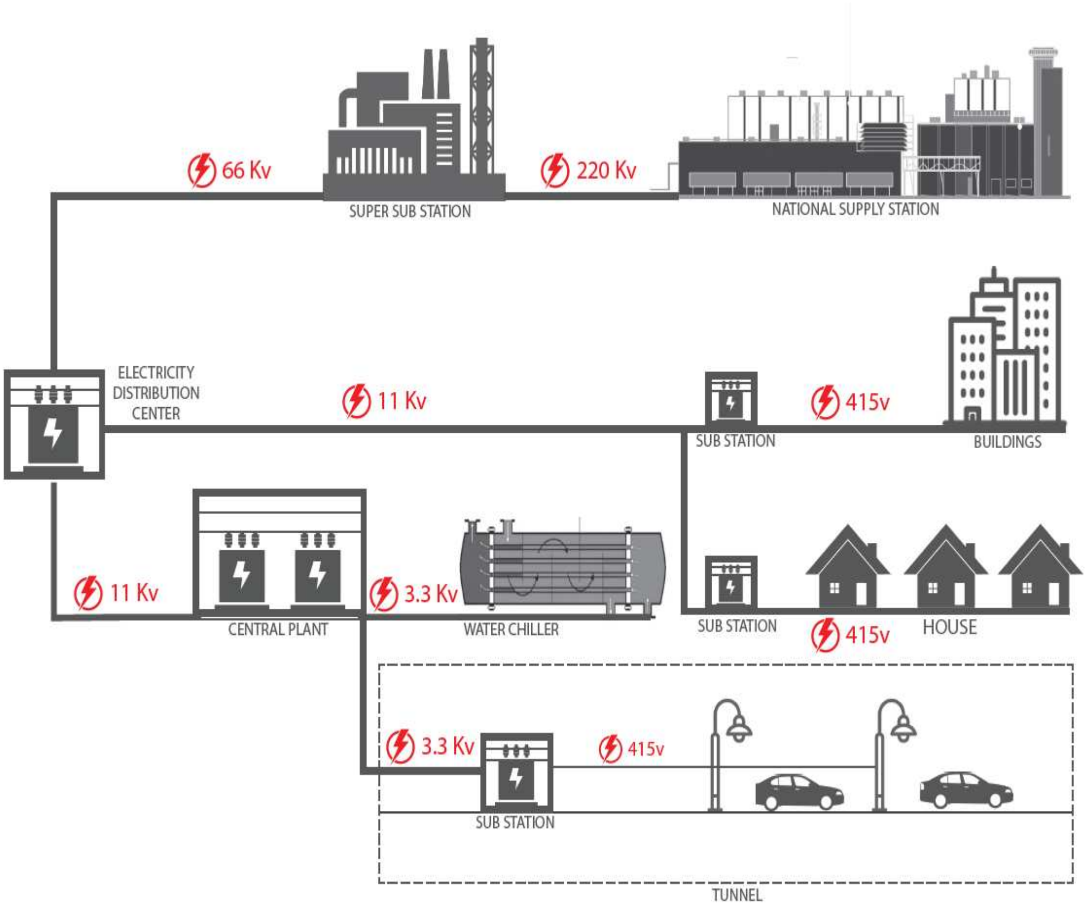


Figure 4.1 Electrical distribution system in the Education City

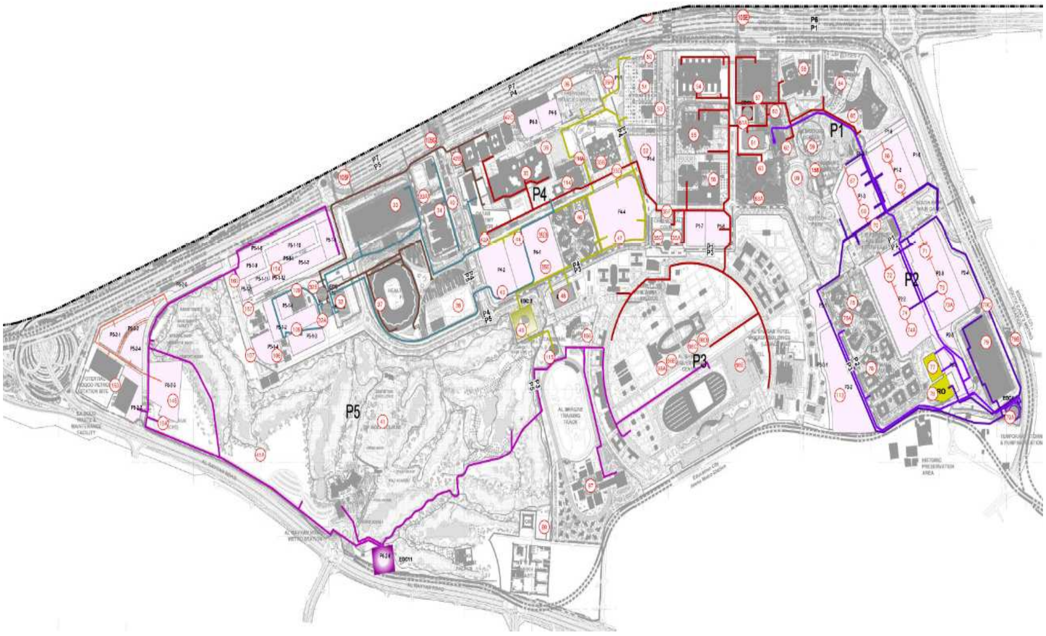


Figure 4.2 Electrical Distribution system in the South Campus

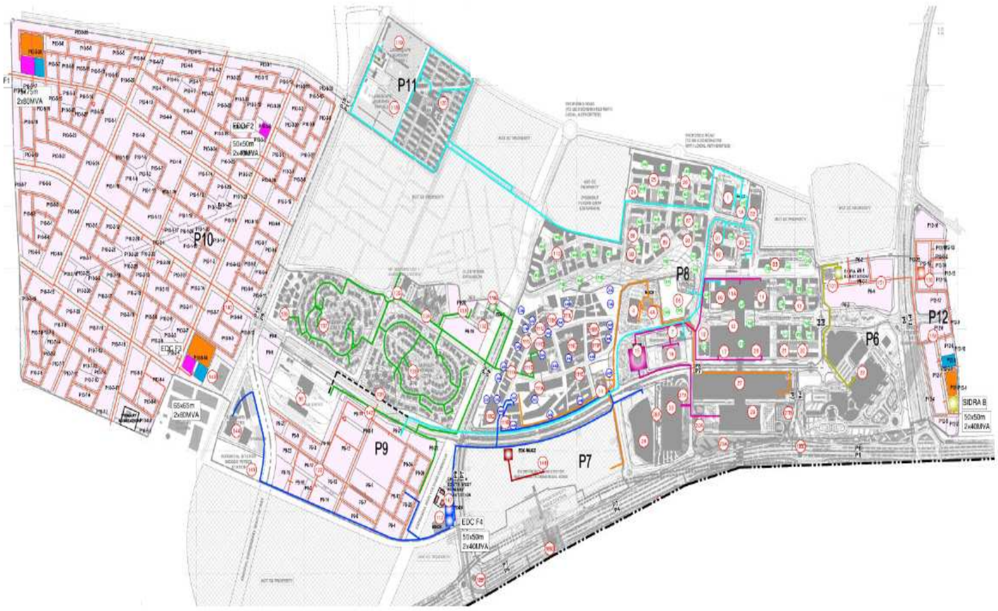


Figure 4.3 Electrical Distribution system in the North Campus

5.3. Power demand

The electrical loads at the Education City are mixed with a combination of commercial, residential and educational facilities and industrial. The later represents most of the load (+50% at summer peak season). These industrial loads are characterized by chiller motors in the district cooling plants, which supply cooling services of all buildings and facilities of the Education City.

A number of EDCs have already been built to provide power to existing facilities and future needs. Table 4.1 provides the capacity and date of installation of the EDC (Electrical Distribution Centers). The capacity varies between 40 and 60 MVA. The first EDC was installed in 2005, while the last one was installed in 2016. 8 EDC were installed between 2009 and 2011.

The current available electrical capacity is equal to 460 MVA:

- North Campus: 240 MVA
- South Campus: 220 MVA

Table 4.1 Capacity and date of installation of EDC (Electrical Distribution Centers)

Zone	EDC	Capacity (MVA)	Date of installation
North	EDC S	40	May, 2009
	EDC 3	60	Mars, 2010
	EDC 6	60	October, 2009
	EDC 8	40	October, 2016
	EDCSIDRA A	40	Novembeer 2011
South	EDC 1	60	June, 2005
	EDC 2	40	Mars, 2010
	EDC RO	40	May, 2010
	EDC 4	40	Jun, 2010
	EDC 5	40	August, 2010
Total	10	460	

5.4. Assessment and recommendation

5.4.1. HV network

Assessment

The development of the 11kV Distribution Network reached a critical point. Indeed, due to the increase in the number projects, buildings and facilities coming on-line, the firm capacity of the Primary Substations (EDC) is becoming over-reached.

During the Master Plan 18, new requirements were incorporated in the North Campus. Several challenges were overcome to meet the electrical demands of the RDC Project which was top priority for Qatar Foundation. RDC Master Plan Project was assigned to EDCs 6, 8 and 9 as well as the supply for the QA Sidra School which was assigned to EDC9. Nevertheless, it was highlighted that only the demand assigned to RDC Master Plan was the whole demand initially available for the entire Master Plan, and there are still several plots without load allocation due to the lack of spare capacity available at EDCs 8 and 9.

In the North Campus new requirements were added such as the incorporation of the project loads of QF Staff Housing Lots 1 & 2.

In the South Campus new requirements were incorporated. Even when it was stated that the South Campus was much more mature in terms of development, it popped the fact that there was an urgent requirement for the Smart Grid system to be in placed to gather information that could help on the planning activities of the 11kV Distribution Network of Education City.

Recommendations

Regarding power allocations, the main risk is related to future growth and expansions, which could put pressure on some EDCs to start being 'out of firm' again from a design perspective (the 800MVA of allocated capacity from Kahramaa are estimated to be more than enough for now), even with the new demand assessment methodology.

To reduce the breach between building design estimates and actual demand, it is recommended to set up plans to introduce smart metering at the building level, at least to start with pilot metering at some buildings where the current consumption can be considered typical and high enough, so it would produce valuable data for the analysis. This is one of the points mentioned in the new methodology that could help to carry out more precise load forecasting exercise as well as support the case of overcoming some of the constraints impose by current Kahramaa regulations in relation to the building maximum demand calculations.

5.4.2. North Campus

Assessment

Several challenges are still present in the North Campus on the subject of meeting the electrical demands of the QSTP extension areas, and other considerations are still there as the likely need to incorporate an additional CP.

Comparing the total loads assigned to existing and future planned EDCs in the North Campus, it is shown that there is still some margin, until reaching the whole firm capacity (around 16 MVA). Nevertheless, there is a large amount of plots whose load has not been assigned to any EDC, whose preliminary estimations give figures of around 100 MVA to be allocated, and there are even more plots whose GFA have not even been given in this Master Plan, so the load has not been considered and that can drive further the available firm capacity needed in the North Campus.

Recommendation

The supply strategy to the RDC Master Plan consists on servicing bulk power to two switching stations inside the RDC project plot. Only the demand assigned to RDC Master Plan consist of the whole demand initially available for the the entire QSTP Master Plan, and there still are several plots without load allocation without spare capacity available at EDCs 8 and 9.

At the moment, the North Campus has an outstanding capacity of around 12 MVA. Nevertheless, there is a large number of plots in the pipeline whose load has not been assigned to any EDC, which envisaged a future capacity shortfall which could be even larger than 100 MVA. This issue should be addressed in subsequent revisions.

On top of this, the full load of QF Staff Housing has been already allocated to EDC8, and it has reduced the spare capacity of EDC8 to serve the estimated power requirements of the RDC, so at the time of being reactivated, it will have to be reassessed the way to supply this load between EDC-8, which currently have a very little spare capacity, and EDC-9.

5.4.3. South Campus

Assessment

The South Campus remains stable from power supply perspective. The option to increase the firm capacity of the primary based on Kahramaa operational guidelines where transformers can be load up to 110% during an 8-hours peak based on a thermal recovery cycle of 16 hours is still being discussed. This highlights the urgent requirement for the Smart Grid system to be in placed to gather information that can help on the planning activities of the Education City 11kV Distribution Network.

Looking at the total loads assigned to existing and future planned EDCs in the South Campus, as per Master Plant 20 A, there was a spare capacity margin, until reaching the whole firm capacity of around 50 MVA.

Recommendations

The South Campus has a spare capacity of around 50 MVA which has been captured within the ECMPI and is envisaged to be sufficient to meet the loads of the upcoming developments.

Even when the South Campus remains stable in terms of required capacity, the foreseen capacity shortfall at the North Campus highlights the urgent requirement for the Smart Grid system to be in placed to gather information that can help on the planning activities of the 11kV Distribution Network of Education City. This would considerably help to develop systems to reinforce the North and South Campus each other in those situations when the firm capacity of any of them is exceeded and them mitigate the capacity shortfall efficiently.

5.5. Consumption Metering

Consumptions data are collected manually by the National provider Kharamaa and the Education City Facility Management team. Up to now, the Education City has not installed Automatic Reading Meters, which allow to follow and analyze data consumption at different time scales.

Figure 4.5 shows the location of the 2 965 electrical meters identified in the GIS system of Kharamaa. However, this situation is subjected to changes related to the transfer of these meters to the Education City Facility Management team.

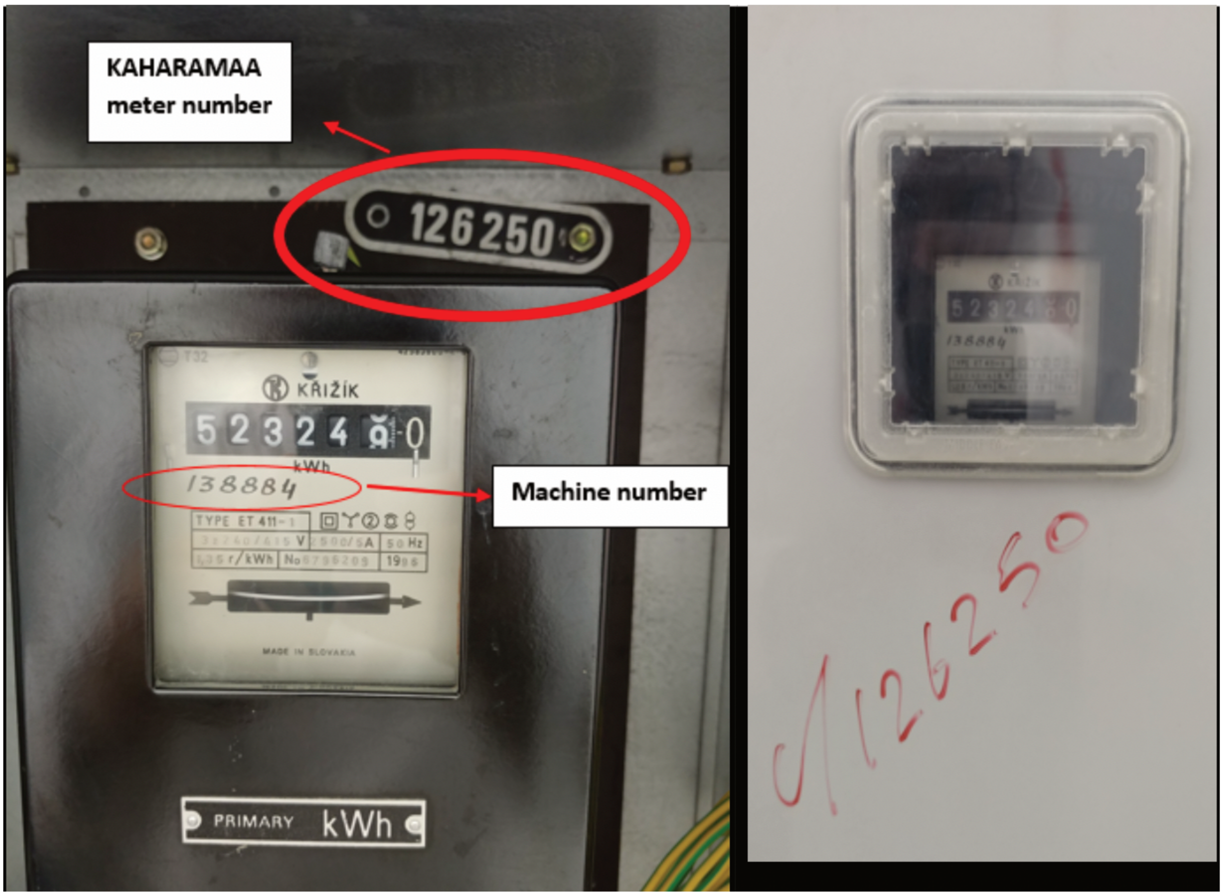


Figure 4.4 Electrical consumption meters – Manual reading

Figure 4.5 Location of the 2 965 electrical meters (Kharamaa)

5.6. Smart Grid Solution

5.6.1. Architecture

The Smart Grid Solution presented in this chapter is inspired from that proposed for SunRise Smart City project (Sakr 2017).

Figure 4.1 shows SunRise platform. It is based on a GIS-based urban information system, which includes the information concerning the electrical network and as its components such as the substations (super-stations, EDS, substations) and electrical meters as well as and data about technical control and maintenance. It contains also data collected via the smart sensors, which are mainly installed in the substations to provide the operating parameters such as voltage, current, frequency, temperature, humidity, air quality and switches status.

The engineering and professional tools are established for the analysis and their use for both optimal management of the electrical network as well as its security. A webserver is used for data display of the data, using graphical tools. This webserver offers the possibility of displaying the campus networks and their interaction, data concerning the consumption at different time and space scales, and alert messages concerning operating faults, maintenance…

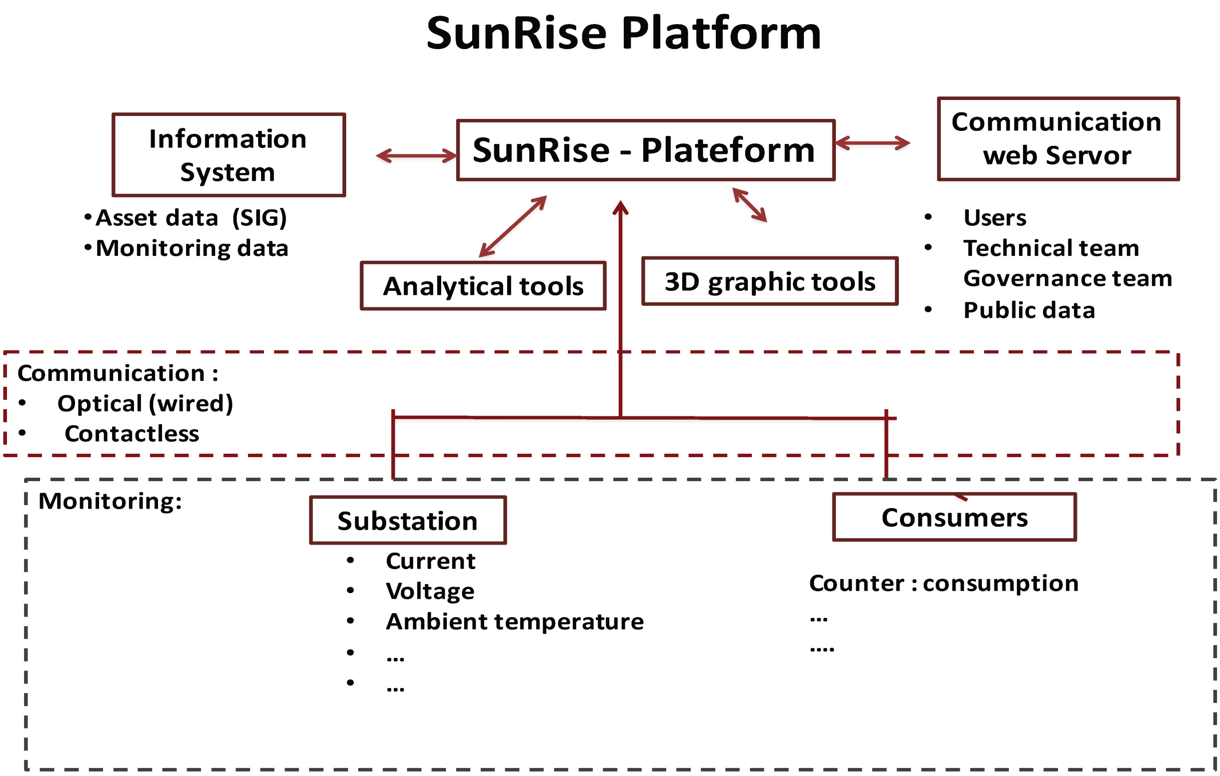


Figure 4.6 SunRise Platform (Sakr, 2017)

5.6.2. Data transmission

A two-way fiber optic communications network is used for data transmission between the platform (Smart Grid server) and the smart sensors as sell as and switches in the substations. The electronic switches can be automatically controlled (open/closed) by the server, as well as by the network manager (remotely/on-site), who can configure, monitor and manage the network remotely. The fiber optic network lines move in parallel with the High Voltage Network, passing through substations.

For security precautions, it is recommended to use a specific fiber optic network, which is independent from that of the Education City.

5.6.3. Data analysis - consumption

Figure 4.7 shows the methodology proposed for analysis of the electrical consumption (Sakr 2017). It includes the following steps:

- Data recording by the smart sensors
- Data transmission via the optic fiber to the platform.
- Data storage, processing and analysis.

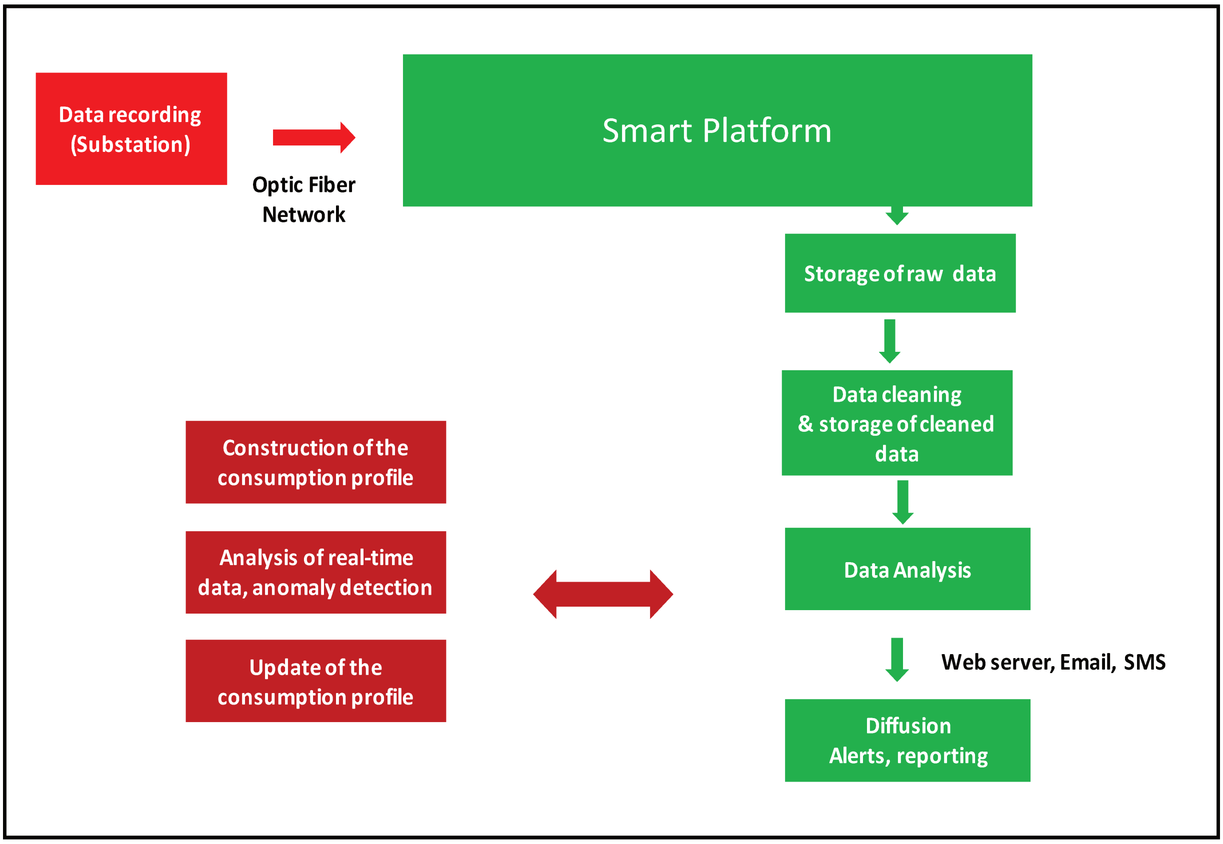


Figure 4.7 Mthodology for consumption analysis (Sakr, 2017)

Data recording and transmission

The first step concerns the measurement of the electrical consumption by the electrical meters installed in the substations and buildings. Each substation also records other parameters related to the electrical grid such as the current, voltage, frequency and temperature.

The substation also ensures the control of the electrical grid through switches. It can isolate the substation from the electrical grid in case of any local fault.

Recorded data are transmitted to the server using the fiber-optic network of the smart grid. The server ensures the management of the electrical grid, particularly the supervision of the grid and rapid intervention in the occurrence of any irregular event, or fault, which could disturb the stable functioning of the grid as well as cause an electrical outage. Since this part of the is very sensitive, and it controls the electrical supply of the campus buildings, infrastructures and research devices, SunRise team did not work on the server.

Data storage, processing and analysis.

The platform stores the raw data in the information system of the Smart Grid by updating the historical data.

Since data could include some imperfections, the platform starts by data verification and phase as follows (Figure 4.8):

(i) Verification of data over the observed period. In the case of absent of data “absence”, the term “lost data” is added to the file. The determination of the “lost data” is carried out using the Artificial Neural Network, trained on historical data.

(ii) Verification of data value. This verification could be easily conducted using the building consumption profile, which will be presented below. If data does not match the consumption profile, the technical staff is informed through email and SMS with mention “out of range data”, which means that it requires additional analysis.

The “cleaned” data is stored in the Smart Grid information system. It could be updated with the arrival of new data to replace the “lost data” or “out of range data”.

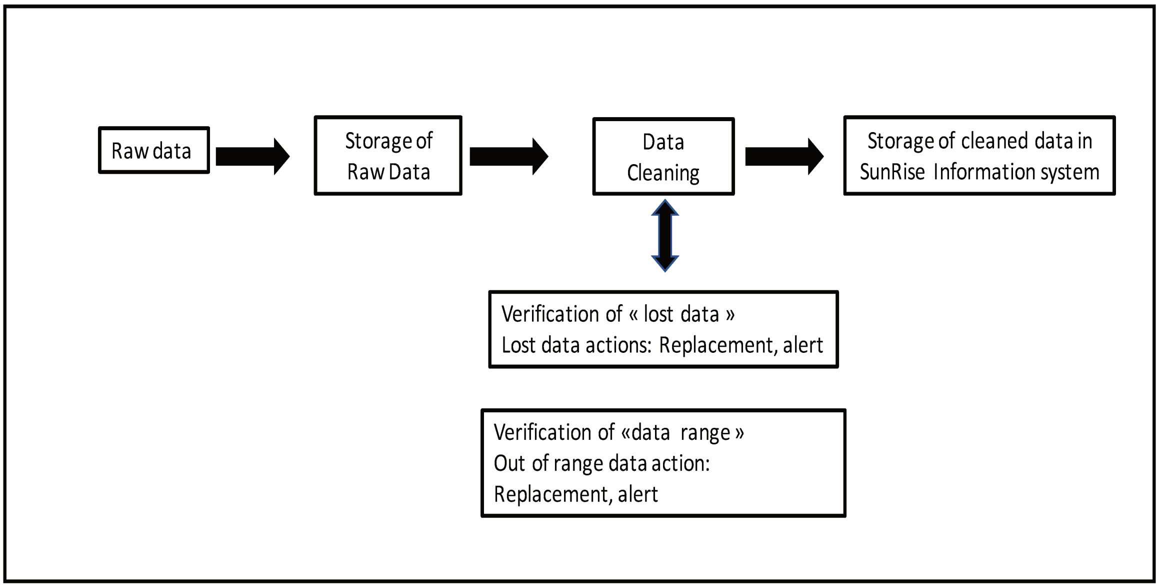


Figure 4.8 Data storage and processing (Sakr, 2017)

Construction of the consumption profile

The construction of the consumption profile constitutes an important step in the analysis of the consumption of any building or group of buildings. It allows the campus managers to understand buildings consumption, to detect anomalies and to conduct performances actions. This construction is based on the analysis of historical data. It should be established at different scales: hourly, daily, weekly and monthly.

Considering the usage of the campus, which is mainly related to academic activity, the daily scale seems to be pertinent. In fact, the consumptions during the weekend and working days could vary significantly. During holidays, the campus activity also slows down.

The construction of the daily consumption profile is conducted as follows (4.9):

- Identification of the "categories" of days, which have a specific consumption profile (week end, working day, summer day, winter day, vacation day, specific event day…etc.).
- For each category and for each hour:
  - Determination of the mean value (V_m), as well as the standard deviation (V_{sd}).
  - Construction of two expected intervals:
    - Interval 1: [V_m-2V_{sd}, V_m+2V_{sd}], which should include 75% of random values

- Interval 2: [V_m-3V_{sd}, V_m+3V_{sd}], which should include 90% of random values

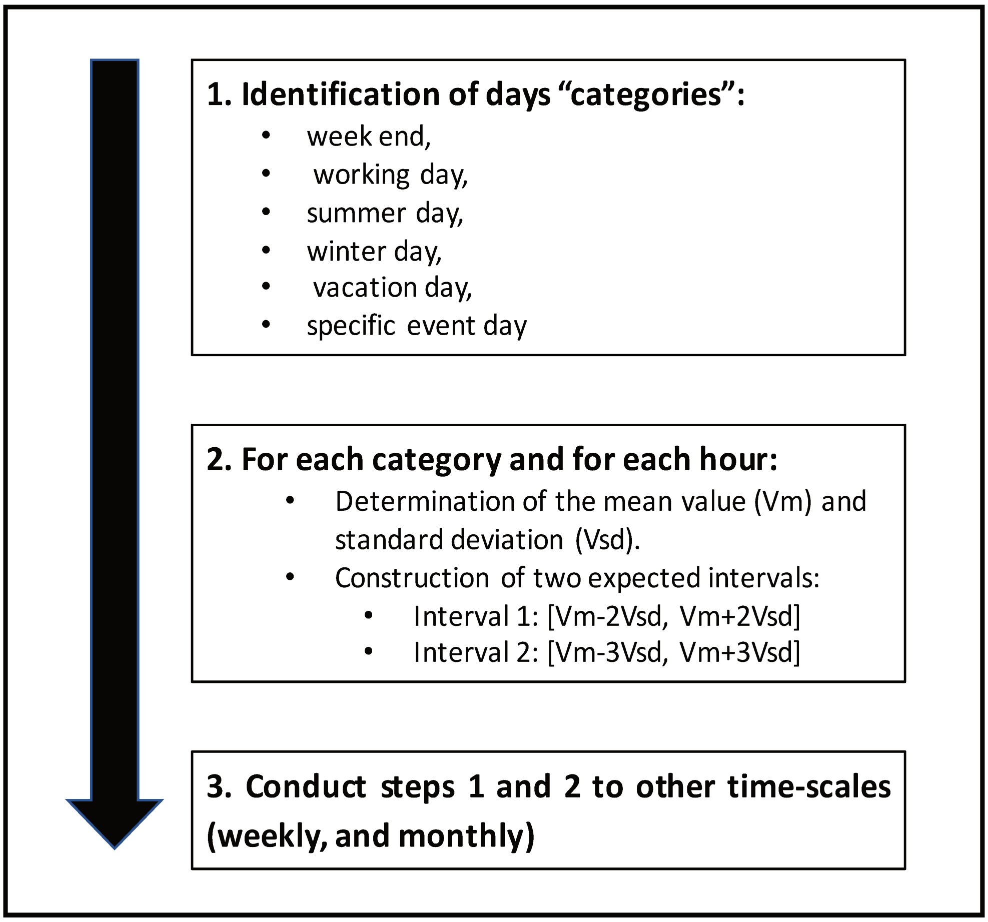


Figure 4.9 Construction of the consumption profile (Sakr, 2017)

To illustrate this methodology, we present its application to SunRise project (Sakr, 2017).

Figure 4.10 shows the daily consumption of the Scientific Campus according to raw data. We observe s three periods with irregularly low consumption:

- From 19 to 21 July 2013: The consumption is around 3.2 MWh, which is very low regarding the campus consumption during summer (around 30 MWh)
- From 7 to 13 November 2013: The consumption is equal to 0
- 18 July (Friday) and 21 July (Monday): The consumption is around 20 MWh, which is low as measured against the consumption of working days in summer (around 30 MWh).

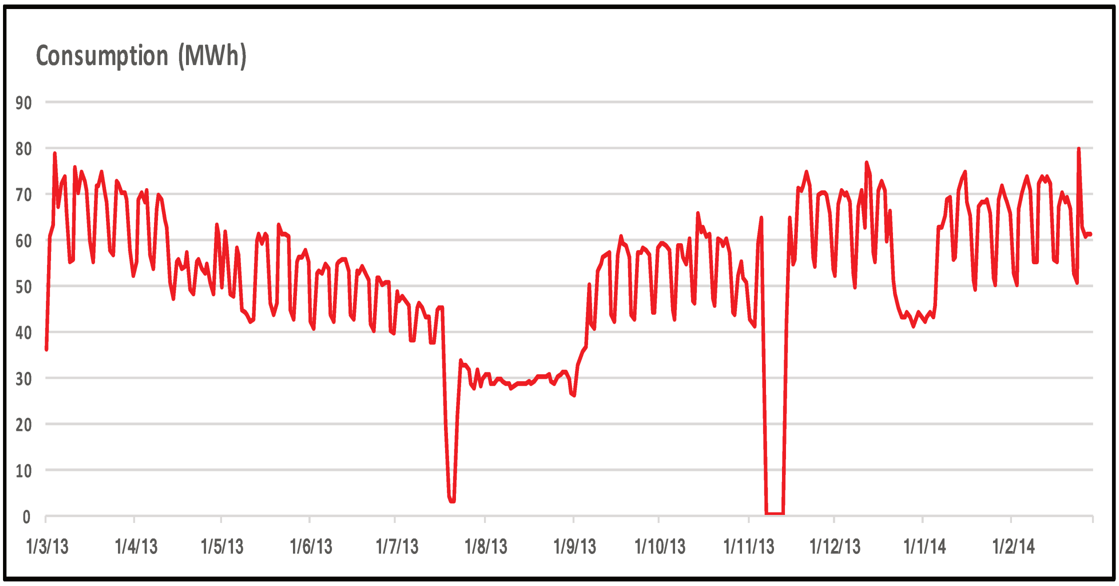


Figure 4.10 Daily consumption of the Scientific campus – Raw Data (Period 1/3/2013 – 28/2/2014) (Sakr, 2017)

According to the methodology presented in the previous section, the "unaccepted data" were deleted. Figure 4.11 displays the cleaned data. We note a more regular consumption profile than that observed with raw data. Low consumptions are observed for the following periods:

- Summer vacation (23july to 5 September) with a daily consumption of around 30 MWh.
- Toussaint vacation (Beginning of November), with a daily consumption of around 40 MWh.
- Christmas Vacation, with a daily consumption around 40 MWh.
- Weekends, the consumption is around 20% to 25% lower than that of the working days.

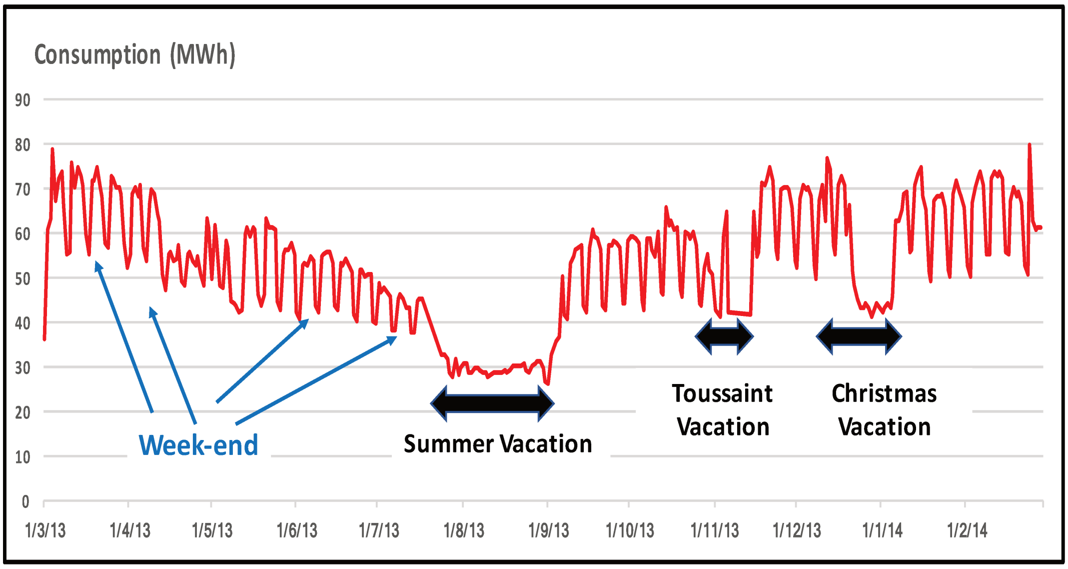


Figure 4.11 Daily consumption of the Scientifiic campus – Cleaned Data (Period 1/3/2013 – 28/2/2014)

According to the consumption variation, the following categories of consumption are identified (Figure 4.12):

- **Categ 1** "Summer Vacation": consumption is equal to around 30 MWh/day. This value is about 56% of the average consumption. It is high if we consider that the main part of the campus activities is not active.
- **Categ 2** "Christmas and Toussaint vacations": consumption is equal to 40 MWh/day.
- **Categ 3** "10 April to 22 July and 6 September to November 6": consumption varies between 40 MWh/day (weekend) and 65 MWh/day (working days).
- **Categ 4** "5 November to 9 April (Christmas vacation not included)": Daily consumption varies between 50 MWh/day (weekend) and 80 MWh/day (working days).

From these categories, we can identify five levels of consumption, which are summarized in Table 4.2.

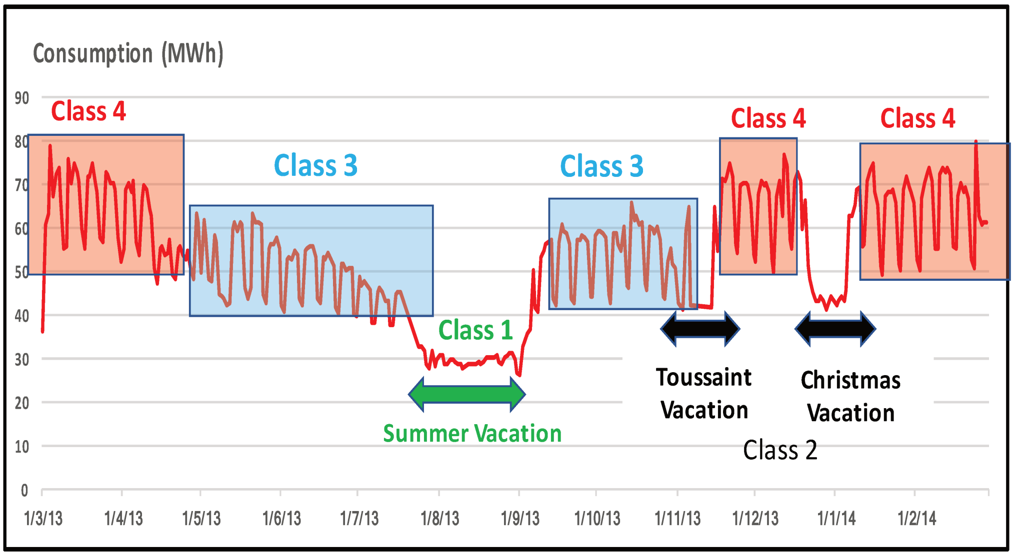


Figure 4.12 Levels of the sciengtific campus consumption (Sakr, 2017)

Table4.2 Levels of the daily consumption of the Scientific Campus (Sakr, 2017)

Level	Consumption	Period
1	30 (MWh/day)	Summer vacation
2	40 (MWh/day)	Class 2 and Week-end of class 3
3	50 (MWh/day)	Week-end of class 4
4	65 (MWh/day)	Working days of Class 3
5	80(MWh/day)	Working days of Class 4

5.6.4. *Data analysis – fault detection*

The Smart Grid aims at rapid detection and localization of faults in order to take the appropriate actions to confine the fault, avoid its extension and establish rapidly the grid integrity. The method is described in figure 4.13.

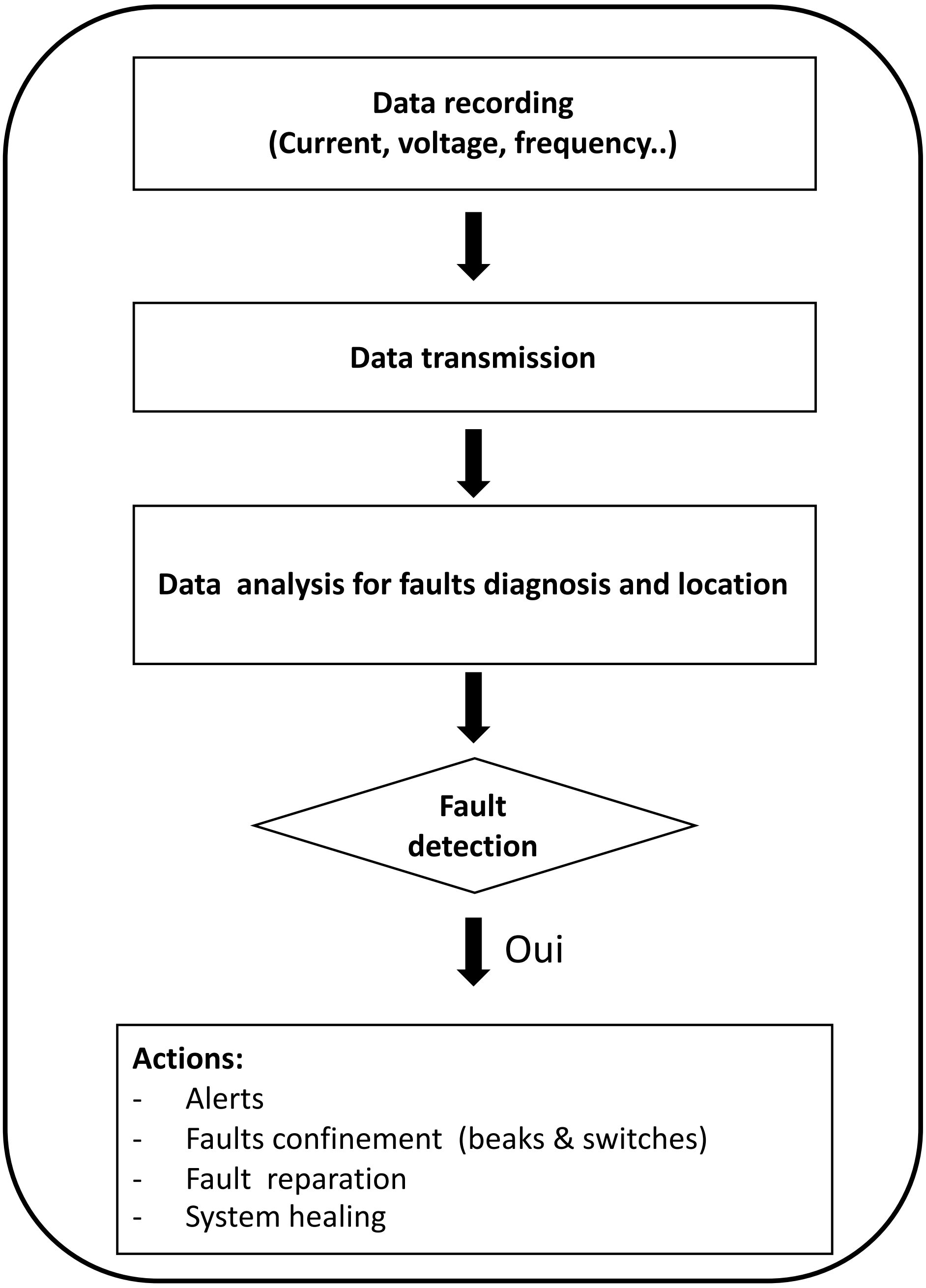


Figure 4.13 : Faults diagnosis and mitigation

Different methods are proposed for fault detection and location.

In the electrical grid, any disturbance that causes a large or sudden mismatch of active power results in a frequency variation (Dong et al., 2007). Based on this result, various methods were proposed for fault detection and identification using frequency signal (Bykhovsky and J. Chow 2003, Bi et al. 2006, Gao and Ning 2011).

On the other hand, voltage and current variations caused by fault can indicate the fault position.

Girgis et al. (1993) and Mora-Florez, et al. (2007) proposed fault location methods for transmission lines using voltage signals. Based on the success of fault detection and location methods, Jiang and Gao (2014) used the Matching Pursuit Decomposition (MPD) for feature extraction and the learning vector quantization (LVQ) network for discriminating different types of voltage signals.

Recently, Dhend and Chile (2016) proposed a method for fault diagnosis in electrical distribution system using the "Symlet Wavelet Function" together with smart sensors that measure the three phase currents.

5.7. Conclusion & recommendations

This chapter presented analysis of the electrical system of the Education City as well as the architecture of a Smart Grid solution for its transformation into a smart grid.

The current electrical system was built by layer to meet the development of the Education City according to the requirements of the period of construction. It focused on the operational part with demand estimated from the design of buildings and facilities. An integrated system was not developed for the management of the electrical system. Consumption metering is still manual, which does not allow to know exactly the buildings demand. The system does not include renewable energy.

With today's requirement concerning sustainability, the transformation of the electrical system into a smart system becomes a "must". This transformation will allow to track the consumption at different time scales and to reconsider the design of EDCs on the basis of real consumptions. It will also ensure an optimal management of the electrical power through energy consumption scheduling as well as the use of storage and renewable energy capacities.

The system will allow also to improve the reliability and safety of the grid by a rapid diagnosis of electrical faults as well as the implementation of a resilience strategy.

This project should start by the smart metering as first step of implementation, within a global strategy of Smart Grid transformation.

5.8. References

- Bi, T. X. Song, X. Wu, and Q. Yang, (2006) “Novel method for disturbance identification in power systems,” in Proc. IEEE Power Eng. Soc. Gen. Meet., Montreal, QC, Canada.
- Bykhovsky A. and J. Chow (2003) “Power system disturbance identification from recorded dynamic data at the Northfield substation,” Int. J. Electr. Power Energy Syst., vol. 25, no. 10, pp. 787–795.
- Dhend MH. & R.H. Chile (2017) “Fault Diagnosis of Smart Grid Distribution System by Using Smart Sensors and Symlet Wavelet Function” J Electron Test (2017) 33:329–338, DOI 10.1007/s10836-017-5658-9
- Dong J. et al., (2007) “Analysis of power system disturbances based on widearea frequency measurements,” Proc. IEEE Power Eng. Soc. Gen. Meet., Tampa, FL, USA, pp. 1–8.
- Gao W. and J. Ning (2011). “Wavelet-based disturbance analysis for power system wide-area monitoring,” IEEE Trans. Smart Grid, vol. 2, no. 1, pp. 121–130.
- Girgis, A. C. M. Fallon, and D. L. Lubkeman (1993) “A fault location technique for rural distribution feeders,” IEEE Trans. Ind. Appl., vol. 29, no. 6, pp. 1170–1175.
- Jiang H. and W. Gao (2014) “Fault Detection, Identification, and Location in Smart Grid Based on Data-Driven Computational Methods” IEEE Transactions On Smart Grid, Vol. 5, No. 6. PP. 2947 – 2956.
- Mora-Florez, J. V. Barrera-Nuez, and G. Carrillo-Caicedo (2007) “Fault location in power distribution systems using a learning algorithm for multivariable data analysis,” IEEE Trans. Power Del., vol. 22, no. 3, pp. 1715–1721.
- SAKR Daniel “Smart Grid deployment and use in a large-scale demonstrator of the Smart and Sustainable City (SunRise): Comprehensive analysis of the electrical consumption.

6. Conclusion

This research concerned the transformation of the Education City of Qatar Foundation into a Smart City. This City constitutes an excellent example for the transformation of existing cities, which were built with requirements lower than that imposed today regarding sustainablity and efficiency.

Presentation of the Education City

The first part included analysis of the current situation of the Education City, with a specific focus on governance, the master plan, and facility management system. It showed that the governance model concerned mainly public actors. It is well established with clear roles for the founder (Qatar Foundation for Education, Science and Community Development), the Board of Directors and Executive Office. However, this system does not include independent hosted entities, which use their own strategies and systems for Facility Management. Integration of these entities in the governance system is recommended in order to establish a global strategy for the Education City development and involve all the stakeholders in this development.

Concerning the master plan, the Education City was built on an area with existing infrastructures. It is compozed of 2 zones (North and South) with indepednt infrastructures and facility management sytems. Each zone includes center plants, EDC (Electrical Distribution Centers) and Utility Tunnel, which are independent. A global integrated master plan for the Education City is recommended for optimal facities management. Concerning utilities, they are organized into 2 groups: (i), The water system which uses central plants and the Utility Tunnel for drinking water, irrigation, sanitation, storm water and chilled water. This system does not include smart metering and (ii) The eclectrical system which uses EDC (Electrical Distribution Centers) and substations for the electrical supply. The electrical grid is not installed in the Utility Tunnel. Consumptions are collected manually.

The Facility Management System includes a large number of systems and applications for the Operational Systems (OS) and Industrial Control System (ICS). An integrated Facility Management System is required for data collection and share, data analysis, decision-making, performance analysis, asset management, operation optimization, safety and optimal investement. This system should be based on the latest technology, that uses smart monitoring, advanced analysis tools and sysyem control.

This resarch focused on the transformation of the water and electrical services into smart systems.

Trasnsformation of the water system

The water system ensures services related to potable water, irrigation, chilled water, storm water, foul water and fire protection. The system is deployed independently in the North and South campuses. It is organized in 3 parts: (i) the central plants, which ensure water storage and supply for the different services, (ii) he utility tunnel, which hosts the main pipe to supply the service nodes (buildings, hydrants, irrigation station,..) and (iii) the services nodes, which ensure the different water services

The water system was built according to the requirements of the construction time. It suffers from fragmented management, lack of monitoring, lack of cooperation between central plants and campuses. The monitoring system does not allow rapid detection of leak or fault operating.

In order to improve the water service management, a smart water system is proposed with:

- Integrated platform for the management of water services
- Integrated information system, which includes asset data as well as operating data
- Data analysis tools, including engineering and Artificial Intelligence tools
- Data visualization and system control

For each water service, the thesis described the challenges of the smart system, smart monitoring, data analysis as well as system control. Thanks to the smart system, water leak and contamination could be rapidly detected, flood risk impact is reduced, the control of the fire water devices is improved, and the irrigation system is optimized. The proposed smart water system could be easily extended to incorporate smart maintenance.

Trasnsformation of the electrical system

The electrical system was built by layer to meet the development of the Education City according to the requirements of the period of construction. It focused on the operational part with demand estimated from buildings and facilities design. An integrated system was not developed for the management of the electrical system. Consumption metering is still manual, which does not allow to know exactly the buildings demand. The system does not include renewable energy.

With today's requirement concerning sustainability, the transformation of the electrical system into a smart system becomes a "must". This transformation will allow to track the consumption at different times scales and to reconsider the design of EDCs on the basis of real consumption. It will also ensure an optimal management of the electrical power through energy consumption scheduling as well as the use of storage le and renewable energy capacities. The system will allow also to improve the reliability and safety of the grid by a rapid diagnosis of electrical faults as well as the implementation of a resilience strategy.

Implementation

The implementation of the Smart City solution should start by smart metering in order to track water and energy consumption, detect rapidly abnormal event and re-design the water and energy systems based on real-data.

It requires also the construction of the smart city platform that coordinates operation and tasks related to the smart city management: construction of the digital model of the Education City, data collection, data analysis, data visualization and system control.

7. *References*

- ABOU RJEILY Yves (2016) "Management and Sustainability of Urban Drainage Systems within Smart Cities" Université de Lille, 2016.
- Anthopoulos, L. (2015) "Understanding the Smart City Domain: A Literature Review" In Transforming City Governments for Successful Smart Cities, Springer, SBN-10: 331903166X
- Bi, T. X. Song, X. Wu, and Q. Yang, (2006) "Novel method for disturbance identification in power systems," in Proc. IEEE Power Eng. Soc. Gen. Meet., Montreal, QC, Canada.
- Buchholz, BM., Styczynski, Z. (2014). « Smart Grids – Fundamentals and Technologies in Electricity Networks », Springer Vieweg, ISBN : 978-3-642-45119-5.
- Bykhovsky A. and J. Chow (2003) "Power system disturbance identification from recorded dynamic data at the Northfield substation," Int. J. Electr. Power Energy Syst., vol. 25, no. 10, pp. 787–795.
- Chen M, Mao S., Liu Y.(2014) "Big Data: A Survey", Mobile Networks and Applications, Volume 19, Issue 2, pp 171–209.
- Dhend MH. & R.H. Chile (2017) "Fault Diagnosis of Smart Grid Distribution System by Using Smart Sensors and Symlet Wavelet Function" J Electron Test (2017) 33:329–338, DOI 10.1007/s10836-017-5658-9
- Dong J. et al., (2007) "Analysis of power system disturbances based on widearea frequency measurements," Proc. IEEE Power Eng. Soc. Gen. Meet., Tampa, FL, USA, pp. 1–8.
- El-Hawary ME. (2014). "The Smart Grid—State-of-the-art and Future Trends", Electric Power Components and Systems, 42(3–4):239–250.
- Gao W. and J. Ning (2011). "Wavelet-based disturbance analysis for power system wide-area monitoring," IEEE Trans. Smart Grid, vol. 2, no. 1, pp. 121–130.
- FARAH Elias (2016) « Detection of water leakage using innovative smart water system- Application to SunRise Smart City Demonstrator» Université de Lille, 2016
- Frye W (2008) Transforming the electricity system to meet future demand and reduce
- greenhouse gas emissions. Cisco Internet Business Solutions Group.
- Girgis, A. C. M. Fallon, and D. L. Lubkeman (1993) "A fault location technique for rural distribution feeders," IEEE Trans. Ind. Appl., vol. 29, no. 6, pp. 1170–1175.

- Hossain MR, Oo AMT, Ali ABMS (2013) “Smart Grid” Chapter 2, Smart Grids Opportunities, Developments, and Trends,(Ed. A. B. M. Shawkat Ali), Springer, DOI 10.1007/978-1-4471-5210-1.
- Iea (2011) “Technology Road Map – Smart Grid”, available on line :
- https://www.iea.org/publications/freepublications/publication/smartgrids_roadmap.pdf
- Islam MF., Amanullah M. T. Oo, Chowdhury SH (2013) “The Traditional Power Generation and Transmission System: Some Fundamentals to Overcome Challenges” Chapter 1, Smart Grids Opportunities, Developments, and Trends,(Ed. A. B. M. Shawkat Ali), Springer, DOI 10.1007/978-1-4471-5210-1.
-
- Jiang H. and W. Gao (2014) “Fault Detection, Identification, and Location in Smart Grid Based on Data-Driven Computational Methods” IEEE Transactions On Smart Grid, Vol. 5, No. 6. PP. 2947 – 2956.
- Kueck JD, Kirby BJ et al. (2004) Measurement practices for reliability and power quality. Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831-6285
- Mayer-Schönberger V, Cukier K (2013) Big data: a revolution that will transform how we live, work, and think. Eamon Dolan/Houghton Mifflin Harcourt
- Momoh, J. (2012). «Smart Grid: Fundamentals of Design and Analysis », Wiley-IEEE Press, ISBN: 978-0-470-88939-8
- Mora-Florez, J. V. Barrera-Nuez, and G. Carrillo-Caicedo (2007) “Fault location in power distribution systems using a learning algorithm for multivariable data analysis,” IEEE Trans. Power Del., vol. 22, no. 3, pp. 1715–1721
- Saab Christine (2018)“Smart system for water quality control: feedback from large-scale experimentation”, Université de Lille, 2018.
- SAKR Daniel “Smart Grid deployment and use in a large-scale demonstrator of the Smart and Sustainable City (SunRise): Comprehensive analysis of the electrical consumption.
- Tuballa ML., Abundo ML. (2016). “A review of the development of Smart Grid technologies” Renewable and Sustainable Energy Reviews, 59, pp. 710–725
- UN (2015) "World Population Prospects: The 2015 Revision – Key Findings and Advance Tables" (PDF). United Nations Department of Economic and Social Affairs, Population Division. July 2015

