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REGIONAL POWER GRID ANALYSIS IN A COMPLEX NETWORK TO IMPROVE THE POWER QUALITY

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Abstract: Nowadays need of energy is must. Primary sources, used every day for our livelihood, will not last forever and we will have to face this problem. Even renewable energies, always considered as part of the solution, are not stable enough to substitute or significantly integrate our traditional system. Smart grid researchers try to face these challenges through the proposal of a new concept of intelligent grid equipped with sensors and devices able to constantly monitor demand and supply of the electrical grid. This architecture willbe able to direct energy only where and when it is needed, avoiding waste and improving power quality at the same time.

I. INTRODUCTION

Today’s energy distribution system is inadequate to meet the growing demand for energy and, at the same time, stem the slow decline of natural resources. Even the U.S. electrical grid, once envy of the world, is no longer world-class. The traditional Electricity delivery network consists of two primary and codependent systems: the EMS (Energy management system), which is the control center for the Transmission grid that delivers energy from power plants to transformation substations, and the DMS (Distribution management system), which is the control center for the distribution grid that connects the substations to the final consumers. This type of network is considered unidirectional, since energy flows only from production sites to consumers. In the smart grid paradigm, instead, we define a bidirectional network, in which not only energy, but also information, are exchanged in both directions. The whole architecture can be represented like the one in the fig 1. As we can see several actors are included in the framework:

- The customers can ensure smart consumption, enabling demand response and providing useful information to the system. Also, as explained in future grid requirements, even the consumer will be able to contribute energy locally thanks to solar panels or electric vehicles, giving it to the system when not needed. Projects such as Smart Homes and BACS (Building Automation and Control System) are currently under development.
- The Bulk Generation maintains the same function of the traditional power plants, but optimized for smart generation. The use of power electronics will be increased in order to control harmonics, fault ride through, and fluctuating generation from renewable sources. Also, increased flexibility will be provided in order to promote cooperation between renewable and conventional Fossil Power Plants.
- The Operation System includes the network control centers for EMS and DMS and is responsible for blackout prevention
- The Electricity Market system will provide price information to the costumers, depending on the condition of the grid.
- The Service System will offer potential for a wide range of new service developments. New business models may emerge due to the opportunities of future Smart Grids.
- The Power Grid System includes all the features that manage and optimize devices and subsystems within the grid. It includes IT integration systems in EMS and DMS, substation automation and protection, power quality and power monitoring systems, decision support systems, and Smart Meter like AMI(Advanced Meter Infrastructure),
- Communication System as a whole is the back bone of power grid infrastructure, and allows exchange of information on a syntactic and semantic level, ensuring privacy, observability and controllability.

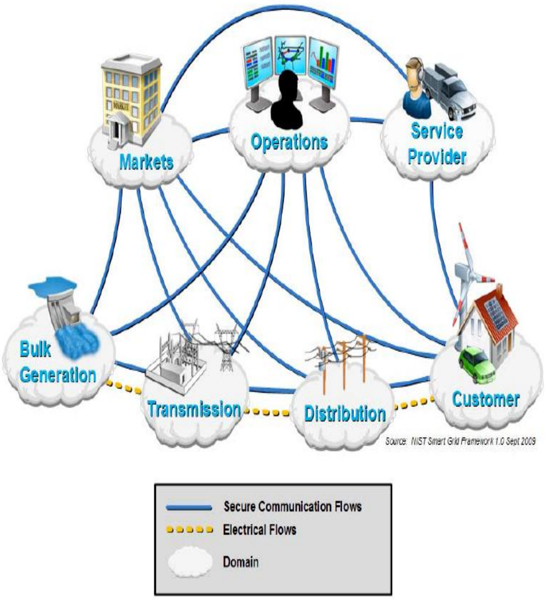

Figure 1 – NIST conceptual model

This paper is focused on the operations system, particularly on the analysis performed to identify weaknesses within a grid. In section II, we present a short recap of the smart grid use cases, exploring their functionality and challenges in order to give the reader an overview of the research carried out so far. Then, in section III, we explain how the test model of Sardinian power grid was built, at the same time comparing different weights often used to represent the concept of “electrical proximity”. We also introduce our personal weight measure based on power losses. The resulting prototype has an architecture and features that make it compatible also with other network commodities, making it flexible enough to test, with appropriate modifications, other smart grid scenarios (e.g. gas and water). In section IV, we explore the characteristics of the grid using a tool for complex network analysis, and show how the betweenness distribution is different when computed taking into account the weights as defined before, compared to the one obtained using the unweighted model. Section Vpresents some conclusions and propose future works.

II. SMART GRID OVERVIEW

Using the term “smart grid” we usually refer to that branch of research that studies and designs networks with the following characteristics. First, an efficient power grid has to self-heal, restoring grid components or network sections when needed; furthermore, it has to protect customers’ privacy, resisting physical or cyber-attacks and providing, at the same time, power quality for 21st century needs; in addition, consumers should be included and motivated toward this initiative considering that their choices and contributions can significantly increase the interaction with the grid, bringing benefits to the whole system. Devices and software used in a grid have to accommodate all generation and storage options, especially for resources with “plug and play” connections, which in a near feature should include new opportunities for more efficient, cleaner power production. According to the U.S. Department of Energy (DOE), a grid with these characteristics can bring the following benefits:

- Elimination of blackouts and cascading out stages.
- Reduction of environmental impact due to reduceddependence from imported fuel.
- Improvement of power quality and competitiveness in the energy market, granting more choices and freedomto customers.
- Reduction of energy losses and more efficient electrical generation should bring new service benefits to customers.
- Access to historical data could be used for future improvements and strategic planning.

Research on smart grid can be faced from several points of view. Many efforts are currently focused on communication intensive IT applications and on the development of reliable TDSOs (Transmission and Distribution System Operators), needed to manage the electric power system. In order to design a proper communication system it is necessary to define a CIM (Common Information Model) usable by all the participating systems and applications via direct interface. A standardized CIM data remains stable, and future expansion or upgrading will be simpler to implement. An IEC (International Electro technical Commission) working group is currently involved in defining the standard for CIM (61970). Data transmission must be ensured by the use of proper protocols, which must be able to forward data over multiple media to a large number of devices, and be flexible enough to change and grow with the industry. Several companies, including CISCO, believe that the Internet Architecture should similarly serve as the foundation for the smart grid, and assume that the IP protocol suite includes a number of protocols and mechanisms apt to ensure high quality of service even with the requirements of the most stringent applications. However it will take years to adapt the IP suite to smart grid architecture, as it will be necessary to create appropriate standards and interfaces. Actually, most of the researches in this field are carried out by private associations, energy companies and standard communities. Setting aside the standards, generally a smart grid can be designed from scratch or from an existing system upgrading it. Both solutions are manageable, but while the first one is too complex, the second one turns out to be slower. To be realistic, a more plausible approach is to make short term decisions that incrementally transform existing distribution system into this smart future vision. These changes have to take into account any weaknesses in the original grid that must be fixed in order to start the process from the most solid base possible. For this reason, topics such as network design, complex networks, optimization, vulnerability analysis and networks data mining are often associated to smart grids.

III. MODEL GENERATION

All modern countries are crisscrossed with high-voltage transmission lines, which transport electrical power from generators at power plants to substations and ultimately consumers. Actually, this architecture can be modeled by graphs, where nodes represent power plants and substations, while arcs represent power lines. In our model, we consider only the EMS and design a graph with 134 nodes and 408 arcs. We define three different types of nodes based on their characteristics:

1. PP or Power Plants. These produce energy to be sent through power lines. They can be defined as source nodes that are always located near substations.
2. UA or Urban Areas. Usually, some substations are located near UAs, and are designed to distribute energy in that district (they define the borders between transmission and distribution system). Each
UA can be seen as a sink node that defines a base level of energy demand, which must be granted in that area to satisfy domestic consumption by their occupants.
3. IA or Industrial Area. Like UAs, IAs are represented as sink nodes that demand energy to satisfy the energy needs of an aggregation of industrial activities absorbed in a unique area.

As we can see in fig. 2, substations are a very important component in a power grid architecture, because they are used to step-up voltage from generators to high-voltage transmission lines, and then to step-down voltage when the energy reaches the DMS. In fact, most transmission lines use high-voltage three-phase alternating current (AC), while single phase AC is sometimes used in railway electrification systems. High-voltage direct current (HVDC) technology is used for greater efficiency in very long distances. High voltage is needed to reduce corona discharge energy loss according to Ohm’s law (R=V/I). In Sardinian power grid we identify three different types of power lines in the EMS.

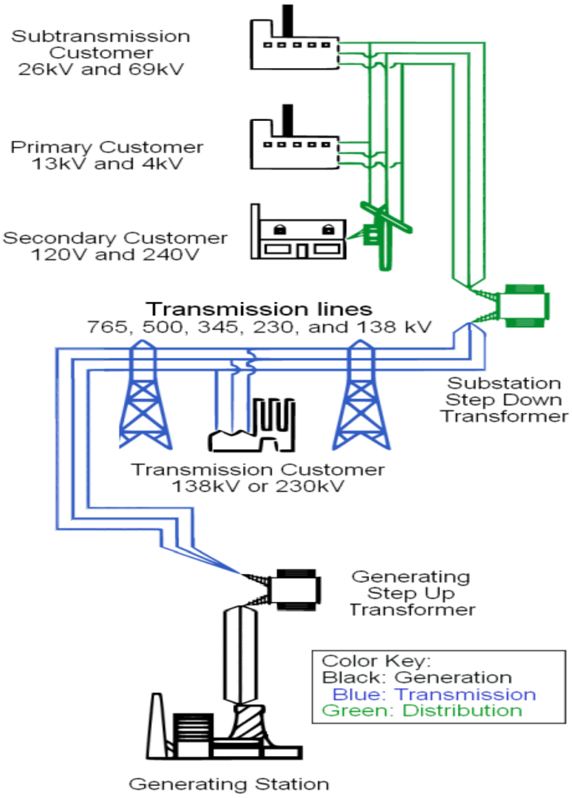

Figure 2- step-up and step-down transformer

IV. COMPLEX NETWORK ANALYSIS

To extrapolate the features of our model we use Cytoscape, an open source platform for complex network analysis and visualization. One of the first representative parameter is the clustering coefficient, a measure of degree to which nodes in a graph tend to cluster together.

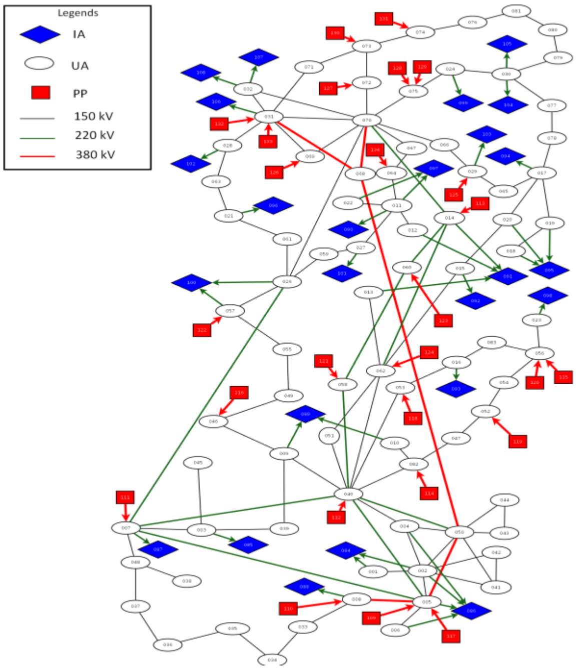

Figure 3- Sardinian grid model

The second parameter analyzed is the network diameter, which is the largest distance between two nodes. Distance is defined as the shortest path length between two nodes n and m. The network radius, on the other hand, is the minimum among the non-zero eccentricities of the nodes (the eccentricity ε of a vertex v is the greatest geodesic distance between v and any other vertex). Diameter and radius are fundamental to depict the characteristics of a grid. Graphs with many vertexes but with small diameter are usually classified in “small-world” category. The higher the diameter, the less a network tends to be interconnected, thus reducing the opportunity to forward energy through alternative paths in case of failures. To introduce the other parameters we need to define the Connectivity as:

$$Connectivity_i = k_i = \Sigma_{j \neq I} \, a_{ij}$$

That in weighted networks equals the sum of weights of the edges incident to i. The average number of neighbors indicates the average connectivity of a node in the network. Anormalized version of this parameter is network density, defined as the mean off-diagonal adjacency, and closely related to the mean connectivity.

$$Density = \Sigma_i \Sigma_{j \neq i} weight_{ij} = S1(k) = mean(k)$$
$$n(n-1) = n(n-1) \; (n-1)$$

where the function Sp(・) is defined for a vector v asSp(v)= vip=(vp)T1 i . The importance of density in a network depends on the specific context. While lower density may increase efficiency in decision-making and allow for more connections outside the network, it can also lead to fewer shared resources and less involvement in that particular network. Likewise, while increased density may improve resource sharing within a network and indicate higher involvement among actors, it can also lead to a more difficult decision-making process and less involvement of actors outside the network.

V. CONCLUSION AND FUTURE WORK

In this paper we build a model of our power grid in Sardinia. Our aim is to analyze how the grid works, evaluating its weaknesses and merits in order to check its predisposition to become a smart grid. The model was built using statistic data about energy production and consumption from Terna, except for arc weights computed with a formula obtained by merging notions of basic physics and notions of “electrical proximity”. We depict our model using complex network parameters computed with the aid of Cytoscape, and we show how betweenness distribution changes introducing weights in the model. However, we are aware that power grids, as stochastic environments, cannot be entirely represented by these analyses. For this reason, in the next months, we are going to test our model with several optimization algorithms, trying to consider the saturation of connections and exploiting the flexibility of the graph to adapt smart grid concepts to other environments.

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