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Smart Grid - reliability, Security, Self-healing standpoint, and state of the art

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Abstract The industrial revolution in various fields has led to an increased demand for energy. Consequently, this has led to many challenges, not only for generation stations but also for distribution stations.
This rise in energy demand pushed the system to be more complex which led to a substantial increase in the requirements for greater reliability, efficiency, security, and environmental and energy sustainability concerns. This great development in networks provoked many companies to switch to using smart methods, which is currently known as "smart grid"
Because of the disadvantages of the traditional grid. The smart grid is considered the best solution for improving the traditional grid. Both grids are similar, but the smart grid makes all parts of the traditional grid smarter in order to achieve the aims we needed from the smart grid. This paper aims at giving an overview of the smart grid and discuss some results of smart grid generation. The system has been validated by MATLAB Simulink software.

Keywords:. Smart grid, wind generation, PV generation.

1 Introduction

Both traditionally controlled systems and centrally controlled systems used to distribute electrical energy have been used for too many years now. It's mostly known as the power grid. Even with the advancement of technology, electric grids globally have had similar structures, dynamics, and principles since the early use of electricity. These traditional power grids are mostly focusing on a few of the basic functions such as the process of generation, distribution, and controlling of electricity. The form of the electricity grid present nowadays is unreliable due to the relative increase in transmission losses, sometimes even power quality that is relatively poor, prone to brownouts, continuous blackouts in addition to the inability to provide adequate electricity leading to discouraging the integration of distributed energy sources. When it comes to both monitoring and real-time control in the traditional non-smart systems, there's a noticeable lack of methods available, which gives a tough opportunity for smart grids in order to provide a real-time solution.

Smart Grid technology provides a solution to generate electric power and an efficient way to facilitate both transmission and distribution of this power. Which can be more easily installed because of its versatility, and it also needs a lesser space in comparison to traditional grids. The smart Grid design concept is aiming at making observation of the grid available, making it possible to control assets and enhance both the performance and the security of the power system with regard to the economic aspects and costs of operations, maintenance, and planning. Smart Grid research has come a long way since the beginning of its first-ever concept available for implementation in 1997. This paper will give an overview of the smart grid and will give some results about smart grid generation.

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2 Definition and characteristics of smart grid

The smart grid is the traditional grid, with all parts being smart, meaning smart generation, smart transmission and distribution, smart loads, smart control, smart metering, smart protection and ……etc.[1]

a) Smart generation system

Using renewable energy sources like wind, PV, fuel cells, hydro, geothermal, biomass.…etc, instead of greenhouse gasses. And connect the micro-grids with the power grid in order to make the grid efficient for power demand from consumers.[1]

b) Smart transmission and distribution system

Meaning using advanced devices (like FACTs) to achieve the aims of the smart grid from reliability, self-healing, and other aims.

c) Smart communication system

Meaning using advanced communication devices in connecting different parts of the power system to achieve the aims of the smart grid.

d) Smart loads system

Meaning using electronics in the loads to become smart and reduce the pollution that comes from loads. Due to the presence of one of the biggest problems which are pollution because of traditional gas vehicles, the use of electrical vehicles provides a proper solution to this problem.[1]

e) Smart control system

Meaning using advanced control systems (like intelligent control) to achieve the aims of the smart grid.

f)Smart metering system

It works on providing direct communication with wireless data protocol, in order to provide the most

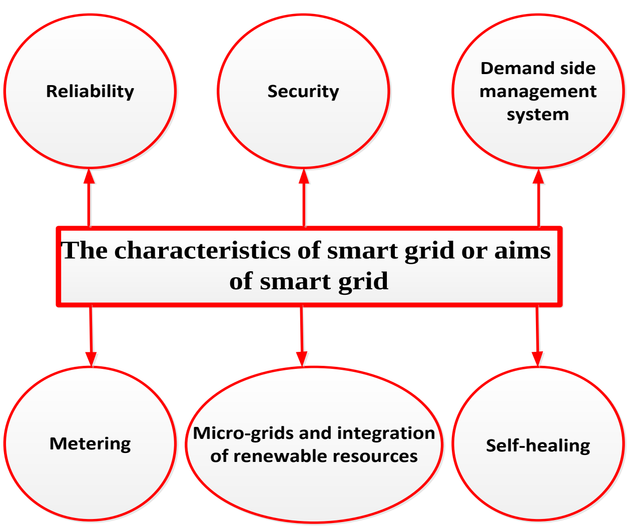

Fig. 1 the aims of smart grid

accurate and precise reading & so a meter reader won't be needed in order to measure consumed energy on consumer premises.[2]

g) Smart protection

Classical protection techniques are categorized into three different types: Protection against possible overcurrent known as overcurrent protection, distance protection, and differential protection. One of those protection methods is dependent on intelligent relaying [3]. The characteristics are mentioned in [1].

3 Research on the smart grids

Many types of research on smart grid systems are available, and some of them are mentioned in this paper.

This research can be classified into two categories, reviewed research like both paper [1] and paper [2], while the rest of the papers provided are like reminder papers according to the point discussed in each paper.

In paper [4], a discussion shows that in smart grids, smart sensors are used to detect both real-time data and the status of bidirectional flows of energy in order to monitor, protect, and control grid operations allowing the improvement of both its reliability and resilience. However, there's a major challenge for smart grids which is Smart sensor data interoperability.

In paper [5], it provides a discussion that concludes there are significant impacts that affect both the development and popularization of EVs which are mainly caused by the battery life of electric vehicles (EVs). It also provides a method to stabilize the EV charging system voltage to improve battery life and charge efficiency on a smart grid by using superconducting magnetic energy storage (SMES) in order to stabilize the EV charging system voltage so it would improve battery life and the charging efficiency on a smart grid.

In paper [6], it discusses voltage and congestion management in order to provide a solution for the distribution of energy trading in a smart grid. In this proposal, by using distributed consensus algorithm the energy trading is being formulated to minimize the costs of functioning generation to supply enough demand. This approach previously described is mainly designed for directed communication networks.

In paper [7], it interprets that certain requirements should be achieved by Power distribution systems such as high reliability, efficiency, and penetration of renewable energy generators (REGs) in a smart grid. Generally, power distribution systems possess a radial nature. Which has the advantage of being a one-way power flow. However, bidirectional power flow is due to the introduction of REGs.

In paper [8], it concludes that in order to provide an affordable, reliable, and sustainable supply of electricity a modern power grid needs to become smarter. So, in US and Europe, a considerable effort has been carried out in order to formulate and promote a proper vision for the development of future smart power grids.

In paper [9], it tells us that the smart grid has increased the deployment of data generation devices such as sensors and

smart meters. The data amount expected to be collected tremendously keeps on increasing. What became a challenging matter is the collection of data that is secure, efficient, and also scalable.

In paper [10], there is a detailed description of electric grids in the future that interprets in detail the role of advanced

sensing systems. Everything is described in detail with regard to the project, the development, and the experimental validation of a smart power meter. An outline has been provided by the authors to elaborate on the potentialities of the sensing systems and IoT in order to efficiently observe the energy flow among nodes of an electric network.

In papers [11] to paper [19], some points of research about the smart grid systems in different fields.

4 The smart generation system

As mentioned above, using renewable energy sources like wind, PV, fuel cell, hydro, geothermal, biomass.…etc, instead of the greenhouse gasses. And making the grid efficient in order to match the needed power demands from consumers. Two sources of renewable energy have been discussed in order to help solve the problem of pollution and to make the grid efficient for power demands from consumers. The two sources are wind turbines and PV cells.

a) Wind turbines

Within the course of the past two decades, due to the cost increase, limited reserves, and adverse environmental impact of fossil fuels, renewable energy sources have been attracting great attention. nowadays, due to technological advancements, cost reduction, and governmental incentives, some renewable energy sources have become more competitive in the energy market. One of them is wind energy which is considered to be one of the fastest growing renewable energy sources in the world now. In this research, we use the Variable-Speed Systems with Reduced-Capacity Converters for its advantages and found a lot in the market.

In Fig.2, A typical block diagram of the doubly fed induction generator (DFIG) wind energy system is shown. By using power converters, Adjusting the power factor of the system is carried out at which the converters only have to process the slip power in the rotor circuits, which represents almost 30% of the generator’s rated power, which results in reducing converter cost in comparison to the wind energy systems that use full-capacity converters.

There is a noticeable increase in the speed range of the generator which is due to bidirectional power flow in the rotor circuit, this is mainly due to the use of the converters. This system features significantly improve the overall power conversion efficiency, extends the generator speed range (±30%), and enhances dynamic performance in comparison to the fixed-speed WECS and the variable resistance configuration. These features have made the DFIG wind energy system widely accepted in today's market.

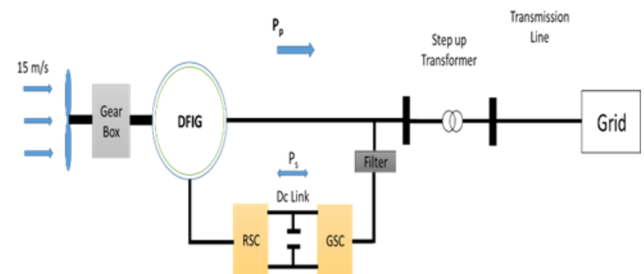

Fig. 2 Variable speed configuration with reduced capacity converters

b) PV Generation System

The practical model of PV cells can be simply represented with a controlled current source by the irradiation level (G) and the cell temperature (T). This current source is connected in parallel with a diode and a resistance that refers to the current drop of the cell; this combination is cascaded by a series of resistance for voltage loss; the overall model is shown in Fig. 3.

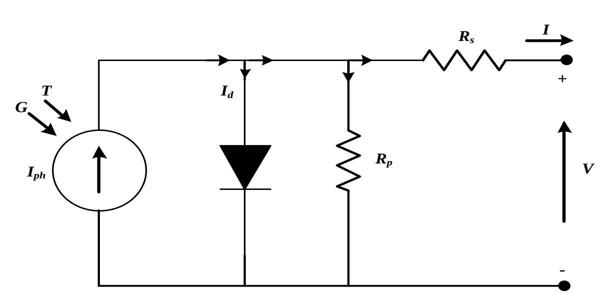

Fig. 3 Actual model of PV cell

The relation among the output PV cell current as a function of the cell parameters can be formulated as [20] :

$$I = I_{ph} - I_o\left(e^{\frac{q(V+IR_s)}{nKT}} - 1\right) - \frac{V + IR_s}{R_p} \qquad (1)$$

where; the I_{ph} is the current generated by the incident light (it is directly proportional to the sun irradiation), I_o is the reverse saturation or leakage current of the diode, q is the electron charge ($1.6\times e^{-19}$ C), K is the Boltzman constant ($1.38\times e^{-23}$ J/K), n is the idealization factor, T is the temperature of (p-n) junction, R_s and R_p are the series and parallel resistance of the cell, respectively, I is the load current, and V is the cell voltage.

Fig. 4 shows the PV plant system connected to the grid. In addition, the different part of the system is presented also in this figure.

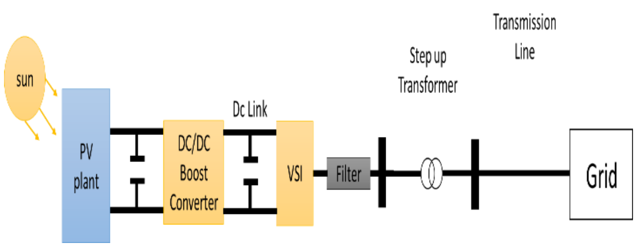

Fig. 4 PV plant system connected with the grid

5 Simulation results

The system shown in figure 5, is the construction of a traditional grid, it consists of generation, step-up transformer, transmission line, step-down transformer, and load. This system can be made smart by putting renewable generation with the traditional generation in order to achieve increased reliability in the system, stability of the system, and ensure system suitability with the increase of the demand in the load.

For these reasons, we can make the system like figure 6, we add a wind generation system with a PV generation system to produce a hybrid renewable generation system with the traditional system to become a smart system as mentioned above.

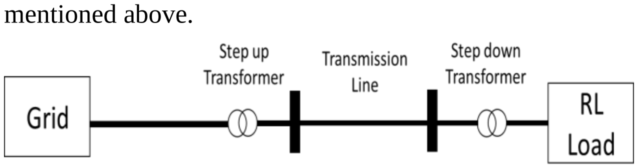

Fig. 5 Traditional grid

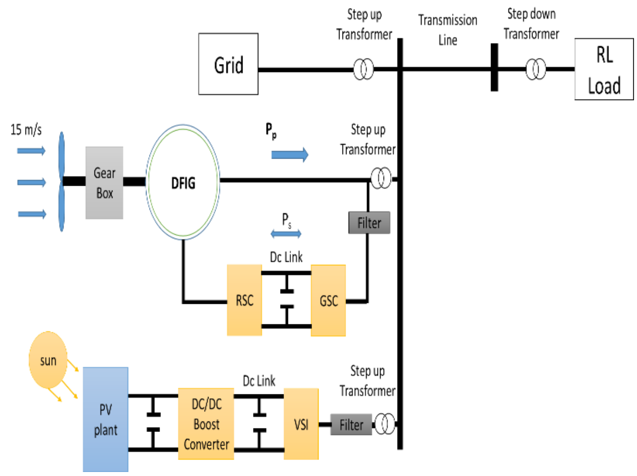

Fig. 6 Smart generation grid

The scenario of power feeding has been validated vai the system shown in Fig. 6 and the results have been listed as shown in figure 7,8,9,10. The voltage and active power at the generation side and load side similarity and all load demands come from the grid. But in figures 11 and 15, the voltage of grid and load similarity after putting the hybrid renewable generation means that the synchronization between a traditional grid and renewable energy has occurred. And in Figures 12,13,14, and 16, the active power of the load is shown in figure 16 after adding hybrid renewable energy as before, but distributed on the three sources traditional grid and wind generation, and PV generation. This increases the reliability and stability of the system and makes it ready for any increase in demand. This means that some goals of smart grid systems have been achieved.

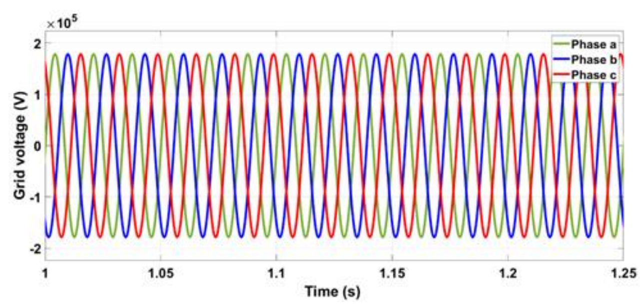

Fig. 7 grid voltage of traditional grid system

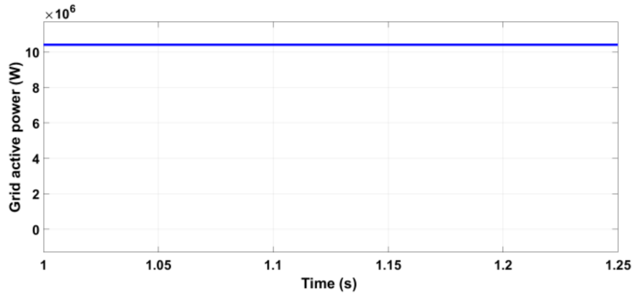

Fig. 8 grid active power of traditional grid system

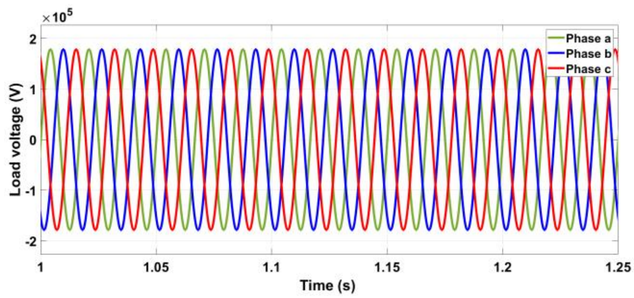

Fig. 9 load voltage with traditional grid system

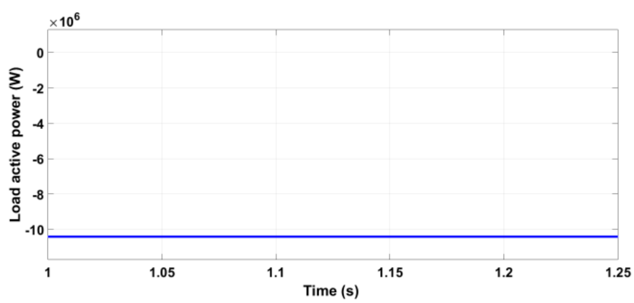

Fig.10 load active power with a traditional grid system

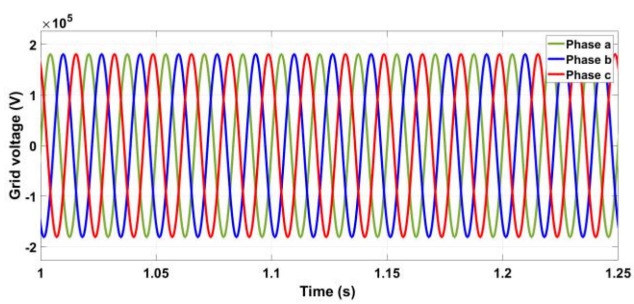

Fig. 11 grid voltage of traditional grid system with renewable energy sources (smart grid system)

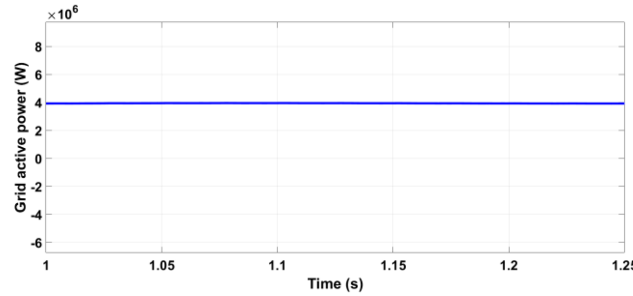

Fig. 12 grid active power of traditional grid system with renewable energy sources (smart grid system)

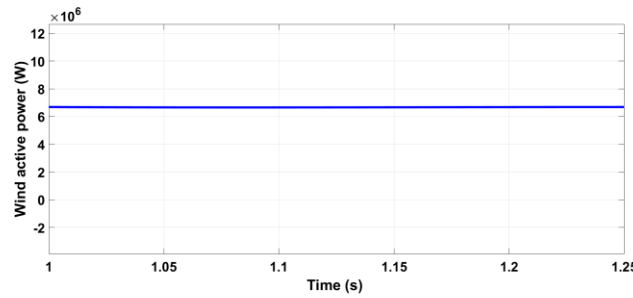

Fig. 13 wind active power

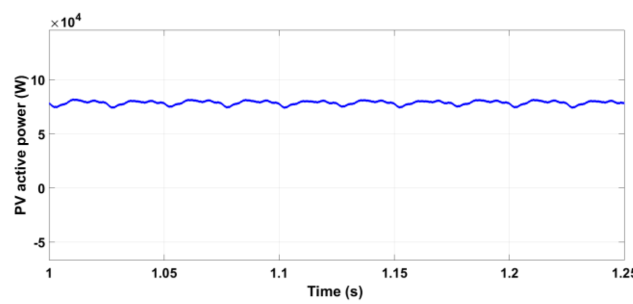

Fig. 14 PV active power

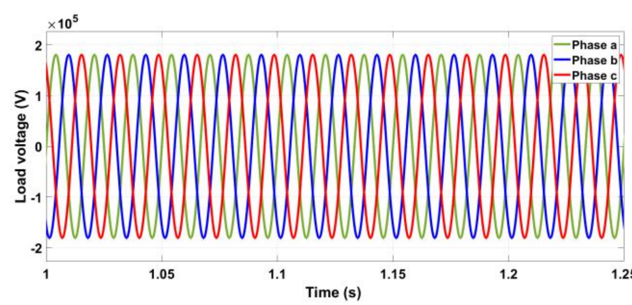

Fig. 15 load voltage with traditional grid system with renewable energy sources (smart grid system)

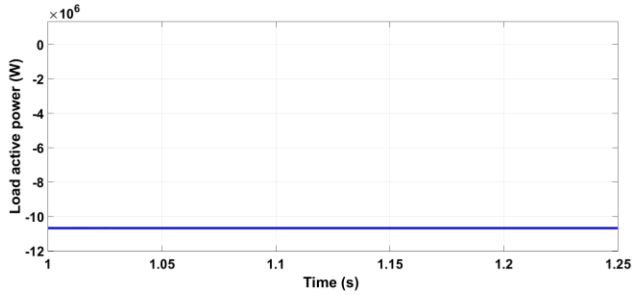

Fig. 16 load active power with traditional grid system with renewable energy sources (smart grid system)

any practical or operational issues involved in performing the study and any issues not covered in other sections.

6 Conclusion

As mentioned above, we defined the smart grid, described the characteristics of the smart grid, knowing the parts of the smart grid, and known some research points about the smart grids.

Provided some information about wind turbines and PV cells as renewable energy sources used in the smart grids with some results about how they work.

Most importantly, we conclude that any improvement in any part of the smart grid considers an improvement in the smart grids themself.

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