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Intelligent Photovoltaic Systems in Power Plants and Other Power Facilities Using Smart Grid Communications Technology

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Abstract: In this study, details of an implementation plan of a 10 kW solar power plant in a typical intelligent electricity network in Mashhad in Iran have been stated. In this plan, all the producers scattered across the city are connected to several centers inside the city through mikrotik radio equipment. The connection between centers is made via. wireless internet. Then, a single information center of scattered solar productions is formed in the center of each province in order to reduce the load production of fossil power plants especially at peak times. To solve the problem in the conditions of lack of a point-to-point connection we use Omni antennas in the receiver which have 360° coverage and do not need direct visibility. Further, if the number of solar power plants (transmitters) is high, mesh network topology is used instead of star topology. In this state, in case of creating obstacles to the transmitter, information of this transmitter automatically reaches the receiver through neighboring transmitters and smart routing. This plan helps to reduce air pollution and develop photovoltaic systems in residential and commercial sectors. Additionally, by implementing this plan we will witness a reduction in fossil fuel consumption.

Key words: Photovoltaic, smart grid, routerboard, Mashhad, transmitters

INTRODUCTION

Population growth and the increasing demand for energy in the future and also running out of fossil fuels have caused the concern for the use of other energies to become a priority. Renewable energies of an inexhaustible source are environment-friendly and available in most parts of the world. Today, we witness a dramatic increase in the activities and investments of governments and private sector companies in the field of research and development and supply of all kinds of new technologies regarding the use of renewable energies in the world which lead to a significant reduction in the actual cost of electricity production from renewable resources and have increased the possibility of their competitiveness with traditional power generation systems. Figure 1 displays the investment status in renewable energy sector by the beginning of 2015. Photovoltaic field is considered among the important sectors of the renewable energy industry which enjoys excellent growth (Viswanathan, 2017). Traditional electricity networks usually do not have the necessary efficiency for the optimal use of energy produced by renewable energy sources. In this regard, making the power grids smart along with renewable electrical energy production assumes especial importance. The works associated with this study can be evaluated in two fields of photovoltaic systems and intelligent electricity networks.

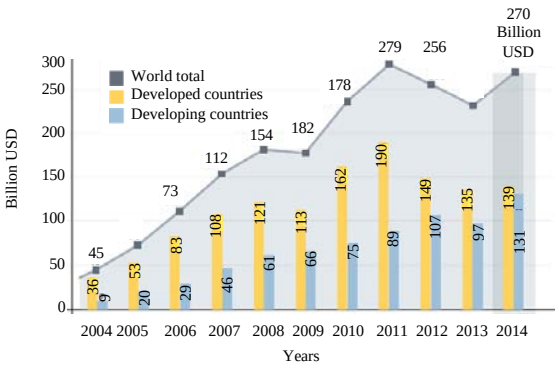

Fig. 1: Investment status of the renewable energy sector (REN21 Policy Institute, 2015)

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START 2004[1]	2013	2014		
POWER				
Renewable power capacity (total, not including hydro)	GW	85	560	**657**
Renewable power capacity (total, including hydro)	GW	800	1,578	**1,712**
Hydropower capacity (total)[3]	GW	715	1,018	**1,055**
Bio-power capacity	GW	<36	88	**93**
Bio-power generation	TWh	227	396	**433**
Geothermal power capacity	GW	8.9	12.1	**12.8**
Solar PV capacity (total)	GW	2.6	138	**177**
Concentrating solar thermal power (total)	GW	0.4	3.4	**4.4**
Wind power capacity (total)	GW	48	319	**370**

Fig. 2: Growth of renewable energy sources by the end of 2014 during 11 years (from 2004-2014); REN21 Policy Institute, 2015)

Extracting electrical energy from sunlight is recognized as photovoltaic conversion. The various components of photovoltaic systems applied in the conversion and preparation of electrical energy produced for end users include photovoltaic panels, inverters, battery and charge controller. Photovoltaic panel which is composed of a number of solar cells converts sunlight to DC electricity. In photovoltaic systems the inverter is known as the heart of the system. In addition to converting the direct current to alternating current, inverters undertake the task of monitoring and controlling the whole system. Besides examining the performance of panels in the radiation conditions proportionate to the maximum power the inverter must continuously monitor the status of the network attached to it.

Today, the need for the photovoltaic system has been well raised in many countries so that it can be regarded as one of the most strategic technologies of the 21st century. As can be observed in Fig. 2, the growth of the photovoltaic system by the end of 2014 is much higher compared to other renewable energy sources such as wind and geothermal energy so that during 11 years (from 2004 up to the end of 2014) it has had >68 times of growth.

The most important factor in selecting the type of the renewable energy includes the climatic conditions. Since in most parts of our county, solar radiation with good angle is the most accessible energy source, the attention of many practitioners in this field has been focused on this energy.

Installed capacity of photovoltaic systems and also the share of different countries of the world in the sector of photovoltaic systems by the end of 2014 have been depicted in Fig. 3 and 4. As can be seen, Germany is ranked first, China has the second place and Japan has the third place.

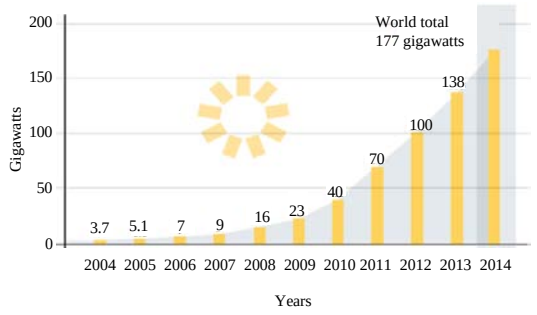

Fig. 3: Installed capacity of photovoltaic systems by the end of 2014 around the world

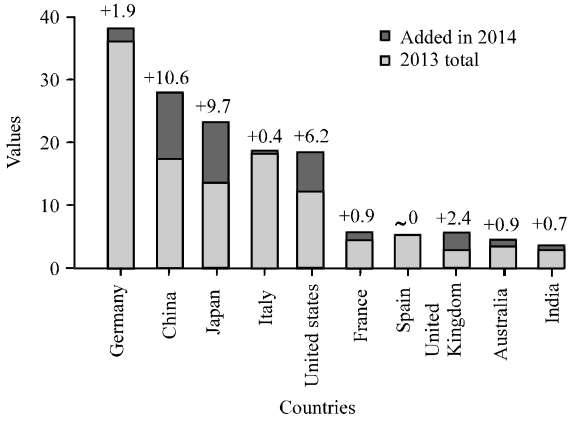

Fig. 4: Share of the leading countries of the world in installing the photovoltaic systems (REN21 Policy Institute, 2015)

MATERIALS AND METHODS

The proposed method: Dispatching access to solar production data for optimal production planning seems

necessary. For this purpose, there is a need for the formation of online centers of solar productions. But the most important issue in the establishment of this center is the use of sustainable telecommunication infrastructure with acceptable security and appropriate cost. In Section 2, we will introduce different telecommunication platforms along with their advantages and disadvantages. In Iran, only two telecommunication platforms, i.e., GPRS and PLC are used to transmit the electricity production data of photovoltaic systems.

In this plan, we intend to connect all the producers scattered across the city to several centers inside the city through mikrotikradio equipment of Sxt/6tant Model. Sxt with a range of 4 km and 6 tant with a range of 6 km fully meet our need in this plan. Besides, considering the little price difference of sxt with GPRS module, the use of sxt in this plan is justified. The connection between centers is established through WiMAX platform. Even the information of all producers can be transferred at a low cost to a single data center in every city that is covered by WiMAX. Also, information is daily stored in the form of an Excel file in one area of the system.

In this study a single data center of scattered solar productions is formed in the center of each province to reduce the load production of fossil power plants, especially at peak times. In the study of photovoltaic system monitoring and two-way smart meters, modern telecommunication technologies are employed to decrease the existing costs and increase security. Moreover, by eliminating the monthly fee for each producer (in case of using GPRS technology) costs are significantly reduced since GPRS technology provider companies receive monthly costs.

The proposed plan has been implemented on a pilot basis in a10 kW solar power plant in Mashhad using mikrotik routerboards of sxt model. If for any reason, the connection between the sender and receiver (control center) is interrupted (e.g,. an obstacle is created over time which interrupts the point to point connection), Omni antennas should be used in the receiver which have 360° coverage and do not need direct visibility. It should be noted that the type of Omni antenna required for the plan is Omni antenna ofMikroTikcompany with OmniTIK5 which is not economically much different fromrouterboard SXT Lite.

Furthermore, if the number of solar power plants (transmitters) is highin our area, we can use mesh network topology or the like instead of star topology. In this state, in case of creating obstacles to the transmitter, information (packages) of this transmitter automatically reaches the receiver through neighboring transmitters and intelligent routing.

For intelligent routing inMikroTikrouter boards, we can act in two ways: in the first method, i.e., Open Shortest Path First routing protocol which is briefly called OSPF, IP of all adjacent router boards (according to mesh topology) is recorded and in case of creating obstacles, the data of a router board is transferred to adjacent router boards according to our prioritization and reaches the receiver through them. In the second method, the routing process is done in the form of IP routes. This protocol is used when we have >3 router boards (transmitter) alongside one another. This means that there is a large number of routes to the receiver and we ourselves can optionally determine a fixed route for each router board to reach the receiver.

This plan finally leads to reduced air pollution and helps the development of photovoltaic systems in residential and commercial sectors. In addition, by implementing this plan, we will witness a reduction in fossil fuels consumption especially in winter through reducing the load production of fossil power plants.

RESULTS AND DISCUSSION

To solve the problem of electrical energy and efficient use of renewable energy sources, the International Energy Agency was established in November 1974 which acts within the framework of the Organization for Economic Cooperation and Development (OECD) in the United Nations. One of the activity fields of the energy agency is the photovoltaic system. In the very beginning, a group called PVPS (Photo Voltaic Power Systems) was formed in the agency, whose mission is to conduct research on solar energy and introduce this renewable source as a reliable energy source. Moreover, this group takes on the task of expanding the use of this energy around the world (Heubaum and Biermann, 2015). Here, we refer to some of the results presented by some member states which are related to our plan.

In July 2002, Ministry of Energy of South Korea started a project called 2010 program solar land whose aim was to install 100,000 solar panels with the capacity of three kilowatts by the year 2010. After completing this project, the data of all panels was transferred to a control center through a monitoring system connected to the inverter. An overview of this project has been shown in Fig. 5 (Kreith and Goswami, 2007).

In Canada like Korea, Xantrex Company which is among the subsets of schneider electric company transferred the panel data to a center through a web server (Designing the software that can be connected to the inverters and decode and detect their coded information).

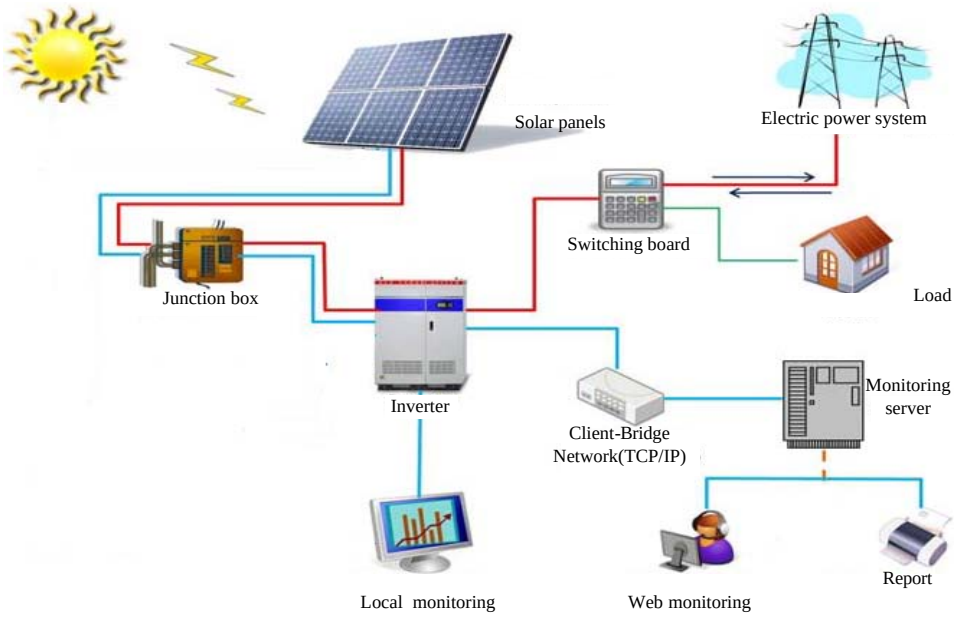

Fig. 5: The plan of the project implemented in South Korea

In October 2005, in Japan, a project called Hachinohe Microgrid Demonstration project was defined in which PLC technology was used to transfer the information of the electricity produced by off-grid photovoltaic systems. This project was completed in March 2008. Besides, in this project, all panels (electricity producers) and users (electricity consumers) were connected to each other by PLC lines and the information about panel production and users' consumption was transferred to a control center in Hachinohe City (Ichiro, 2008).

In Iran, in recent years and with the implementation of rural electrification plan in 2006 which was started from Qazvin Province and was then implemented in Gilan, Zanjan, Boushehr, Yazd and Kordestan provinces, new attention was paid to this industry. In this project, totally the installation of 58 photovoltaic systems with the capacity of 358 kW for the electrification of villages lacking electricity has been successfully performed on a pilot basis.

Afterwards, Shiraz solar power plant whose construction was started from 2000 was completed in 2006. Similarly, this industry was considered in other cities. However, our country does not have a proper place in the operation of this God-given power even in the Middle East. Butit is predicted that according to the law approved by the Iranian government in July 2015, the growth rate of this industry increases considerably.

Since the connection between renewable energy sources and fossil energy is possible only through smart electricity networks, definition of these networks and review of the related materials seem essential. The electricity network is applied to the infrastructure that covers the generation, transmission and distribution of electricity and a smart electricity network is defined by two methods of power flow in electrical networks and information in telecommunication networks (Bayindir *et al*., 2016). The smart network acts similar to the internet network, meaning that components of the modern electricity network including posts, transmission and distribution lines and public and private companies are able to intelligently and efficiently establish two-way communication with each other. This network allows for detecting the rate of energy consumption and applying it for electricity companies using various sensors, wireless communications, advanced software and computing facilities. Additionally, in case of creating problems and blackout in the network, electricity companies quickly notice their incidence and intelligent actions take place on time. Subscribers are also able to manage and optimize their energy consumption. Hence, it is essential that intelligent measurement equipment with the capability of two-way communication be installed at the customer's location. The smart electricity network on the side of the consumers means that they are able to intelligently manage their consumption in order to pay less cost at peak hours when energy prices are high.

Telecommunications are the pillar of the performance of the smart electricity network (Emmanuel and Rayudu, 2016; Ancillotti *et al*., 2013; Kabalci, 2016). To this end, there is a need for a high-speed, secure and resilient

telecommunication network with high reliability and at a reasonable cost between the posts and control center. Thus, the use of new telecommunication technologies in the implementation of smart networks is of crucial importance. These communication technologies are divided into four categories including Power Line Communications (PLC) satellite communications, fiber optic communications and wireless communications.

One of the most important features of PLC system is the use of the existing electrical network and no need to create a new network for the exchange of information. The work of PLC technology is based on the creation of frequency difference. By creating phase difference, PLC system produces the carrier wave by the use of which it transfers the data to the network (Lampe and Berger, 2016; Poudereux *et al*., 2016). PLC system is among the telecommunication platforms in the electricity industry which is quite independent and whose management and control are in the hands of the electricity company. Also, since PLC telecommunication environment is of a cable or aerial wire type its location is easily identifiable in case of the occurrence of errors. Moreover, PLC network development is not complex because access to any part of the distribution network is possible at any time and in parallel, the telecommunication network is expandable. Low maintenance cost and no need for the service of a particular period are other advantages of PLC. On the contrary, impedance changes, existence of random and uniform impulse noise, interference from external sources adjacent to the high tension lines, a large number of branches, low data transfer rate at medium voltage level and high cost of converters and modems are among the disadvantages of PLC.

Satellite communications provide new solutions for remote monitoring and control of posts (Davison *et al*., 2015; Grami, 2016). Satellites provide broad coverage. Therefore, they can be a good communication infrastructure for automating the electrical system in order to access the remote posts. Global satellite coverage has caused the satellite communication to be an affordable solution for the remote posts. Communication via satellite requires no cabling and can be quickly installed and connected to the network by having the necessary technical equipment. On the other hand, round trip time delay in satellite communication is significantly greater than terrestrial communications links. Transport layer protocols like TCP which have been created for terrestrial communication linksare not suitable for satellite communicationsdue to the existence of delay in setting the data rate. Besides, the quality of satellite channels depends onweather conditions and fading effect which decreases the efficiency of the satellite communications system (Davison *et al*., 2015). If no other communication infrastructure is available,satellite communication for remote stations is an affordable solution. But the operating cost of satellites (infrastructure cost and monthly user fee) for all the communication networks of posts is higher than other communication options. In addition, high initial investment costs for "transceiver" are also another limitation of satellite communication.

Optical fiber communication systems which were first introduced in 1960 have considerable benefits relative to the communication systems based on copper wire. By using the high capacity of optical fiber bandwidth, high-performance communication can be provided for automation applications. Current systems of sending the optical fiber provide the transmission speeds up to 10Gbps by the use of sending a single wavelength and provide the the transmission speeds of 40-1600 Gbps by using Wavelength Division Multiplexing (WDM). No significant energy radiates from optical fibers and they do not receive interference from external sources. So, optical fiber compared to electrical transmission is much more secure to blows and is safe from radio frequency interference and electromagnetic interference and mutual inductance. In contrast, although optical fiber networks have several advantages, their installation cost to remotely control and monitor the remote posts is great. Further, reinforcing the optical signal is one of the fundamental problems regarding the optical fiber. To amplify the signal, optical signals should be converted to electrical signals, be amplified and then be again converted to optical signals (Cusatis *et al*., 2006).

Most of the smart network applications use different wireless technologies (Emmanuel and Rayudu, 2016). Wireless communications in smart network are divided into four categories of WiFi, WiMAX, technologies related to mobile network (such as JP Arras and 3G) and wide range radio communications (Grami, 2016).

GPRS is a new value added service in the third generation of mobile phones that allows for sending and receiving information or data on the mobile network (Wancheng, 2012). Indeed, GPRS adds a packet-switched layer to Global System for Mobile (GSM) existing in the mobile phone which is far better than the circuit-switched communication standard of GSM network. Before GPRS, according to GSM network, all the channel capacity was used for calls and data transmission. With GPRS technology, the possibility of the participation of more than one user from one channel is created. The rate of package data exchange in this system ranges between 56 and 114 kB. Use of GPRS has limitations which will be mentioned in the following. The relatively high price of

modules used in the smart electricity network (like bst-347 model) has prevented the expansion of this technology to domestic consumption networks. Besides, since GPRS and GSM use a frequency channel, first, their rate of signal strength constantly changes and second, in crowded cities of Iran such as Mashhad, when the number of mobile usersin one region is greater than the capacity of the cell intended for that region, GPRS is cut off (Kalden *et al*., 2003; Kilpi, 2003). For each period of using GPRS, a bill is issued for the volume that is used and also the subscription fee of the provider company. Although, this amount is not too high for use in smart meters, it significantly increases when the number of subscribers with smart meters is raised.

The 3G or the third generation of mobile networkis a method for data transfer in mobile phones and wireless systems (Ahamed, 2013; Chapman *et al*., 2015; Chung,*et al*., 2015; Xia, 2011). New generation of mobile network has a multimedia approach. 3G unlike GSM which was a generation for voice and data transmission prepares the ground for multimedia transmission. Additionally, its maximum bandwidth reaches 42 Mbps. But radio regulations organization allows for a maximum bandwidth of 4 Mbit.

Almost the same problems of GPRS can be seen in 3G technology with the difference that the cost of its modules is lower and the cost of its bills is higher. The main advantage of 3G compared to GPRS is its broader bandwidth. Equipment of this technology often provided by Micro Tikcompany in fact creates a wireless network with a minimum range of 4 km and the bandwidth of at least 2 Mbps. In these communications, radio waves are transferred in the frequency band of 2.4 and 5.8 GHz (in accordance with 802.11 IEEE standards).

Worldwide Interoperability for Microwave Access (WIMAX) is also an extremely useful and revolutionary wireless method regarding all users' access (at any level) to the internet (Ahmadi, 2011; Kumar, 2008). This nameis taken from the first letters of Worldwide Interoperability for Microwave Access and as is clear from its name, it is a solution for internet access through microwaves. WIMAX works based on the rule ofWi-Fi.WiMAX transfers data between computers by radio waves. A computer that is equipped with WiMAX equipment receives the data from a WiMAX transmitter. Guaranteed communication security, value added service the possibility of providing special services and cost saving particularly the low cost of its modems are among the most important advantages of WiMAX. On the contrary, although WiMAX has been relatively isolated in relation to interfering waves, it is vulnerable to air humidity and environmental conditions influence it.

In the end, it should be said that in the past, the platform of fixed telephone line was used as one of the platforms of data transmission in the electricity network. But in recent years, this telecommunication platform is not used due to its great noise-taking and high cost of PSTN modems and also development of new technologies with broad bandwidth.

CONCLUSION

Given the limitations of fossil resources and destructive environmental impacts, the use of these resources on one hand and increased demand for electrical energy on the other make the use of renewable energy inevitable. Meanwhile, solar energy is considered as one of the most important sources of energy because first, the use of solar energy is free and no country needs to spend money for the use of this energy; but they should invest in technology. Second, in most countries, world population and thus energy use are on the rise and a reliable source of energy should replace fossil fuels. Since solar energy is regarded as a limitless source, it is a safe alternative to fossil fuels.

But the most important issue to replace renewable resources instead of fossil fuels is to have online information on renewable products. Thus, these systems can be efficiently exploited if they are part of a smart electricity network. To exchange information between the components of a smart electricity network, there are different telecommunication platforms each having their own advantages and disadvantages. Therefore, selection of an appropriate telecommunication platform depends on the conditions of the electricity network and environmental conditions and restrictions. Sometimes, the use of a combination of several telecommunication platforms can be effective.

In this plan, all the producers scattered across the city are connected to several centers inside the city through mikrotik radio equipment of sxt/6tant model. Then, the connection between centers is made through WiMAX platform. Besides, a single information center of scattered solar productions is formed in the center of each province to reduce the load production of fossil power plants especially in peak times.

By implementing this plan and decreasing the load production of fossil power plants, fossil fuels consumption decreases in unnecessary times especially in winter which ultimately leads to reduced air pollution. Also, this plan helps the development of PV systems in residential and commercial sectors.

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