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Optimal Embedded Generation (EG) Units for 24 Hour Electricity Supply in Nigeria

Godswill Ofualagba[1], Otega Ejofodomi*[2]
[1]Associate Professor, [2]Lecturer
Department of Electrical and Electronics Engineering, Federal University of Petroleum Resources (FUPRE), Effurun, Nigeria

*Corresponding Author: ejofodomi.otega@fupre.edu.ng

ABSTRACT
This paper proposes embedded or distributed power generation units that are proximal to the electricity distribution networks in Nigeria to solve the power outages currently experienced across the nation. Embedded Generation (EG) Analysis was performed using the Power Optimization Software owned by RACETT NIGERIA LTD. The type of station to be embedded (Solar, Hydro, Wind, Oil, Natural Gas, Coal, or Nuclear) was selected and the state in which the plant was to be installed was also selected, based on the availability of natural resources within the region. The capacity of the EG unit was adjusted until each state in the distribution network received 24 hours on electricity for October 16, 2019. The country requires a 4717 MW solar power plant in Sokoto State, 1671 MW wind power plant in Katsina State, 938 MW hydro power plant in Taraba State, 574 MW hydro power plant in Ogun State, 125 MW hydro power plant in Kogi State, 2031 MW hydro power plant in Benue State, 625 MW natural gas power plant in Delta State, 1135 MW hydro power plant in Anambra State, and 1521 MW hydro power plant in Cross River State.

Keywords-- Electricity generation, distributed generation, solar energy, hydro power, wind energy, coal energy, nuclear energy

INTRODUCTION

The electrical power system in Nigeria is made up of a generation system, transmission system, and distribution system. The generation system in Nigeria currently consists of 23 power generating stations located at remote locations in Lagos, Rivers, Abia, Edo, Bayelsa, Kogi, Akwa Ibom, Cross River, Delta, Ogun, Ondo and Niger States [1]. Fig. 1 shows the generating stations in Nigeria, which consists of 3 hydro power stations in the north, and twenty natural gas power generating stations in the south. Their combined electricity generation for October 16, 2019 was 80,249.18MWH or 3,343.72 MWH/H [2].

Once generated, power it is stepped up to 330 kV before it is transmitted to various parts of the country by the Transmission Company of Nigeria (TCN) [4]. The power is further stepped down to 132 kV as it gets to injections stations close to towns. At injection stations, the power is once again stepped down to 33 kV before it is passed on to distribution networks within the towns and cities. The distribution is split into 11 zones shown in Fig. 2, and the distribution networks comprise 33 kV, 11 kV and low voltage circuits [4]. Within towns, power is stepped down to 11 kV at substations and again finally to 415 V and 220-240 V by distribution transformers before reaching consumers within the towns and cities. Within each distribution region or zone, an electricity distribution company handles the distribution of power received from the Transmission Company of Nigeria to its constituent states. Each distribution company is allocated a certain percentage of the total electricity generated by the 23 generating stations in the nation's electricity grid.

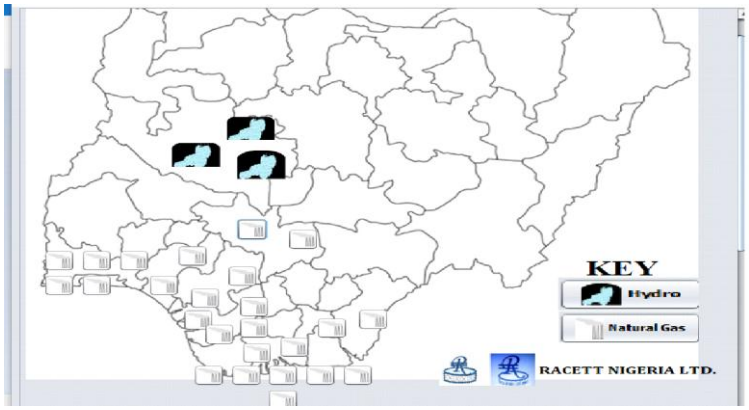

Figure 1: *Power Generating Stations in Nigeria [3].*

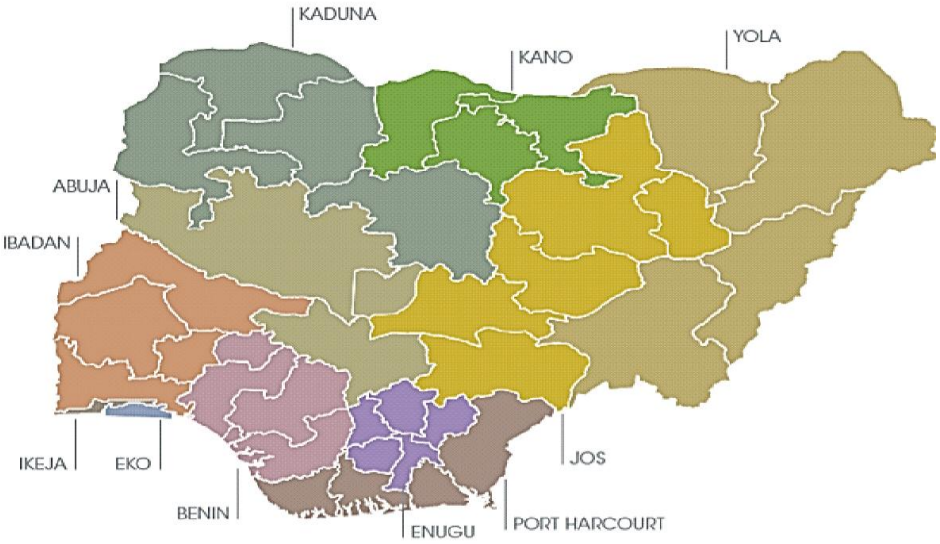

Figure 2: *Electricity Distribution Regions in Nigeria.*

Power Distribution Analysis of the nation's electricity grid showed currently 9 of the 11 distribution networks or regions are presently experiencing power deficits [3, 5]. Table 1 shows the power deficit experienced by each distribution region on October 16, 2019. It should be noted that Eko Distribution Company and Ikeja Distribution Company both distribute electric power to Lagos State only. Their combined received power of 9949 MWH (4331 MWH + 5618 MWH) exceeds the daily power demand of 7660 MW for Lagos State, and so both regions are adequately supplied with electricity.

Table 1: *Power Distribution for Nigeria on October 16, 2019 [5].*

S. No	Distribution Company	States Covered	Daily Power Demand (MWH)	Power received on October 16, 2019 (MWH)
1	Abuja Distribution Company	FCT, Kogi, Nassarawa, Niger	5562	4852
2	Benin Distribution Company	Delta, Edo, Ekiti, Ondo	6157	2798
3	Eko Distribution Company	Lagos	7660	5618
4	Enugu Distribution Company	Abia, Anambra, Ebonyi, Enugu, Imo	7577	2864
5	Ibadan Distribution Company	Kwara, Ogun, Osun, Oyo	7233	4618
6	Ikeja Distribution Company	Lagos	7660	4331
7	Jos Distribution Company	Bauchi, Benue, Gombe, Plateau	6811	1181
8	Kaduna Distribution Company	Kaduna, Kebbi, Sokoto, Zamfara	7664	1362
9	Kano Distribution Company	Jigawa, Kano, Katsina	9227	3138
10	Port Harcourt Distribution Company	Akwa Ibom, Bayelsa, Cross River, Rivers	6533	1636
11	Yola Distribution Company	Adamawa, Borno, Taraba, Yobe	5684	2724

This paper explores how to address or overcome the power deficit experienced by 9 of the 11 distribution regions in Nigeria. It has been noted that the distribution system affects consumers due to the differences in amount of power delivered to them when compared to generated quantity of power because of long distance between the generating station and load centers, due to technical losses [6]. Therefore, if new generating stations are to be installed in the country, they should ideally be located as close as possible to the distribution centers to minimize these losses, rather than concentrated in a certain section of the country. It has been proposed that the six geopolitical zones of Nigeria (South-South, South-East, South-West, North-Central, North-East, and North-West) should draw up a master plan for power generation with Federal Ministry of Mineral Resources in collaboration with the Nigerian Electricity Regulatory Commission (NERC) acting as the

supervisory body [7]. However, a better approach would be to utilize embedded or distributed power generation within each electricity distribution region in Nigeria to minimize technical losses due to electricity transmission.

This paper proposes embedded or distributed power generation that is proximal to the distribution networks they supply. Distribution generation is often used to refer to small-scale electricity generation with a maximum capacity of 50 MW to 100 MW [8-10]. However, the International Energy Agency (IEA) considers embedded generation (EG) as units producing power on a customer's site or within local distribution utilities, and supplying power directly to the local distribution network. In this case, no reference is made to the generation capacity level [11]. Detailed analysis of seven different kinds of power plants (hydro power plants, solar power plants, wind power plants, natural gas power plants, oil-fired power plants, coal power plants, and nuclear power plants) are investigated for embedded generation within each distribution region in Nigeria to determine what kind of generation station should be installed in each region to address the power deficit currently being experienced by each region. The required capacity of the generating station needed to address the power deficit for each region is also determined, taking into account the current transmission and distribution losses experienced by each region. Based on this data, recommendations can be made to the Federal Government on the optimal embedded generation for each of the electricity distribution regions in the country.

MATERIALS AND METHODS

Materials

A Power Optimization Software for Nigeria, owned, developed, and patented by RACETT NIGERIA LTD., was used to study the effect of new generating stations in an electricity distribution region in Nigeria. The software allows users to input the daily power generated by each of the 23 functioning generating stations in Nigeria and from this, calculates the power received by each distribution region (less transmission and distribution losses), as well as the power received by each state in the country. The software is shown in Fig. 3. It also allows the user to design an embedded generation for any state in Nigeria and provides quantitative data of the effect of the embedded generation on the national electricity grid and the local distribution network.

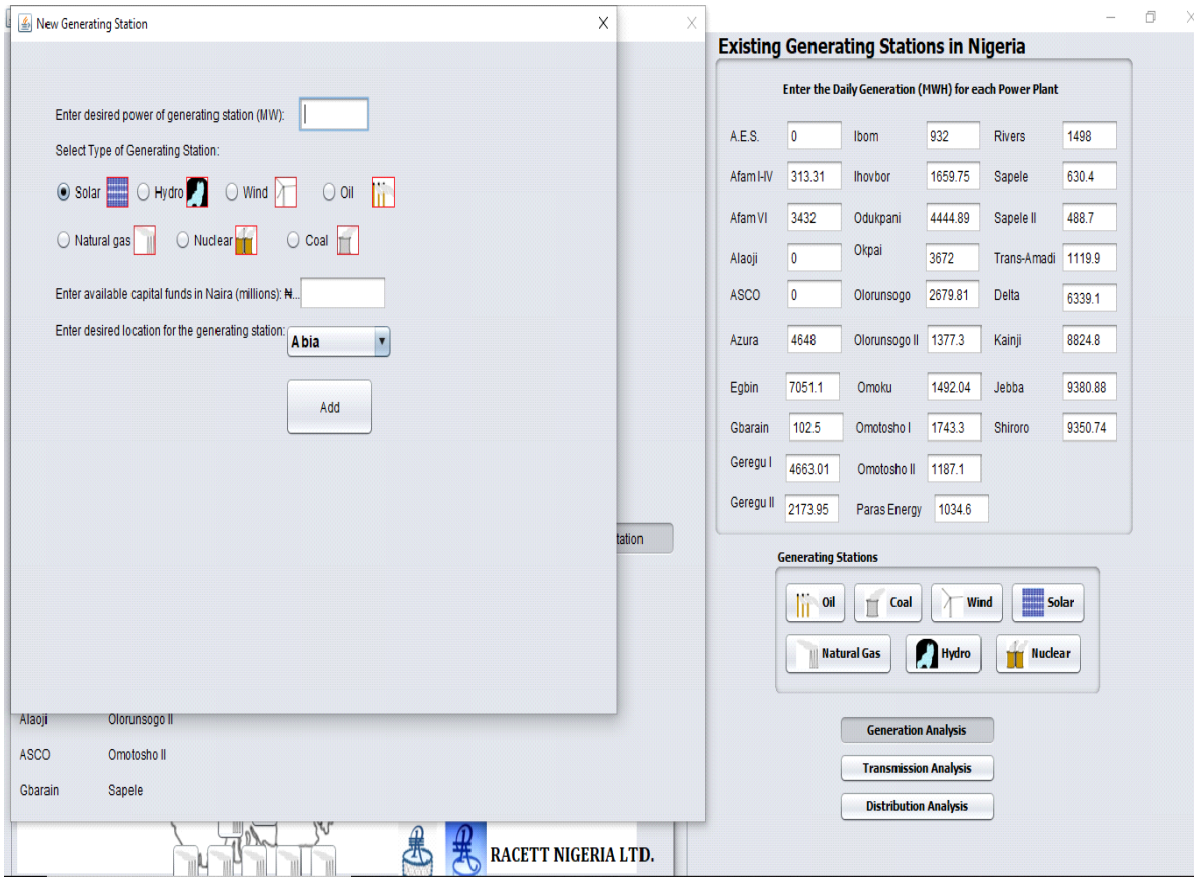

Figure 3: *Power Optimization Software for Embedded Generation in Distribution Regions in Nigeria [3].*

Methods

The power generation data for each of the 23 generating stations in Nigeria for October 16, 2019, was entered into the software tool. From this, the software automatically calculated the power distributed to each state within the nation, and the number of hours of electricity each state received for October 16, 2019. Embedded Generation Analysis was then performed using the same software. The type of station to be embedded (Solar, Hydro, Wind, Oil, Natural Gas, Coal, or Nuclear) was selected and the state in which the plant was to be installed was also selected. States having greater than 2,050 kWh/m2 were classified as having the capacity to own an embedded solar power plant [12]. For Hydro power plants, only states for which the Nigerian Federal Ministry of Power concluded bankable feasibility studies on their dams were identified as possessing the capacity for an embedded hydro power plant [13-15]. Wind energy potential varies with wind speed. Only states with wind speeds above 6.0 m2 were considered viable for an embedded wind power plant [16]. For natural gas and oil power plants, only states with known natural gas reserves and crude oil reserves were considered viable for natural gas and oil power plants respectively [13]. States with economically viable coal deposits were considered for embedded coal power plants [13, 17]. It is reported that Nigeria is in the process of constructing four nuclear power plants with a capacity of 1,200 MW in Akwa Ibom and Kogi. Therefore, the software considered only these two states as viable for possessing an embedded nuclear power plant. Embedded generation analysis was performed for the nine distribution regions currently experiencing power deficits in the country.

After the desired embedded generation plant was selected for a state, the software incorporated the new plant into the national electricity grid and re-calculated the total power supplied to the affected distribution network. The energy sent out by the new generation plant was transmitted directly to the distribution company of that sate, and then shared among the distribution network constituent states based on state population. In other words, the embedded generation plant supplied additional electricity only to the distribution network it was connected to, and not to the entire national grid. In addition to calculating the improved power supply to the affected distribution network, the software also calculated the total number of hours of electricity the distribution network received for that day from both the national grid and the embedded generation plant. Using this statistics, the capacity of the embedded generation plant was adjusted until each state in the distribution network received 24 hours of electricity for October 16, 2019. From this, a list of viable embedded generation plants for the distribution regions in Nigeria was obtained.

RESULTS

Table 2 shows the viable embedded generation plants for each state in Nigeria, and the capacity required in order to ensure 24 hours of electricity each day for the various electricity distribution regions. For the Abuja Distribution Region, a 99 MW coal power plant, a 125 MW hydro power plant, a 178 MW wind power plant, or a 58 MW nuclear power plant is required to address the current deficit. For the Benin Distribution Region, a 625 MW natural gas plant, a 2,587 oil-fired power plant, or a 666 MW coal power plant is required for the region to a constant supply of electricity. Enugu Distribution Region requires a 1,135 MW hydro power plant, a 900 MW coal power plant, an 844 MW natural gas power plant or 3,495 oil power plant to overcome its power deficit.

The Ibadan Distribution Region requires a 674 MW hydro power plant to address its present electricity supply shortage. Jos Distribution Region requires a 2,031 MW hydropower plant, 3,330 MW solar power plants, 2,897 MW wind power plant, or a 1,610 MW coal power plant to receive 24 hours of electricity each day. Kaduna Distribution Region needs a 2,877 MW hydro power plant, a 4,717 MW solar power plant, or a 4,104 wind power plant to address its current deficit. The Kano Distribution Region requires a 1,172 MW hydro power plant, a 1, 921 MW solar power plants, or a 1, 671 MW wind power plant to be able to distribute enough power to guarantee 24 hours of electricity each day. The Port Harcourt Distribution Region requires a 1, 521 MW hydro power plant, a 1, 130 MW natural gas power plant, a 4,682 MW oil power plant, or a 703 MW nuclear power plant to guarantee 24 hours electricity to its constituent states. Finally, the Yola Distribution Region needs a 938 MW hydro power plant, a 1,538 MW solar power plant, or a 1,338 MW wind power plant for the region to recive 24 hours of electricity each day. No power plants were required by the Eko Distribution Region and the Ikeja Distribution Region, as both regions received enough power from the national grid to supply 24 hours of electricty for their constiuent state (Lagos) on October 16, 2019.

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Table 2: *Viable Embedded Generation (EG) plants for each state in Nigeria with optimal generation capacity to ensure 24 Hour Electricity.*

			Capacity sof Embedded Generation to ensure 24 Hours Electricity (MW)						
	Distribution Region	**State**	**Hydro**	**Solar**	**Wind**	**Natural Gas**	**Oil**	**Coal**	**Nuclear**
1	Abuja	FCT	-	-	-	-	-	-	-
		Kogi	125	-	-	-	-	99	58
		Nassarawa	125	-	178	-	-	99	-
		Niger	125	-	-	-	-	-	-
2	Benin	Delta	-	-	-	625	2,587	666	-
		Edo	-	-	-	625	2,587	-	-
		Ekiti	-	-	-	-	-	-	-
		Ondo		-	-	625	2,587	-	-
3	Eko	Lagos	-	-	-	None	None	-	-
4	Enugu	Abia	-	-	-	844	3,495	900	-
		Anambra	1,135	-	-	-	-	900	-
		Ebonyi	-	-	-	-	-	-	-
		Enugu	-	-	-	-	-	900	-
		Imo	-	-	-	844	3,495	-	-
5	Ibadan	Kwara	-	-	-	-	-	-	-
		Ogun	574	-	-	-	-	-	-
		Osun	-	-	-	-	-	-	-
		Oyo	574	-	-	-	-	-	-
6	Ikeja	Lagos	-	-	-	None	None	-	-
7	Jos	Bauchi	-	3,330	2,897	-	-	1,610	-
		Benue	2,031	-	-	-	-	1,610	-
		Gombe	2,031	3,330	-	-	-	1,610	-
		Plateau	-	3,330	2,897	-	-	-	-
8	Kaduna	Kaduna	2,877	4,717	4,104	-	-	-	-
		Kebbi	-	4,717	-	-	-	-	-
		Sokoto	-	4,717	4,104	-	-	-	-
		Zamfara	2,877	-	4,104	-	-	-	-
9	Kano	Jigawa	-	-	1,671	-	-	-	-
		Kano	1,172	1,921	1,671	-	-	-	-
		Katsina	1,172	1,921	1,671	-	-	-	-
10	Port Harcourt	Akwa Ibom	-	-	-	1,130	4,682	-	703
		Bayelsa	-	-	-	1,130	4,682	-	-
		Cross River	1,521	-	-	-	-	-	-
		Rivers	-	-	-	1,130	4,682	-	-
11	Yola	Adamawa	-	1,538	-	-	-	-	-
		Borno	-	1,538	-	-	-	-	-
		Taraba	938	-	-	-	-	-	-
		Yobe	-	-	1,338	-	-	-	-

Using the data provided in Table 2, the optimal embedded generation power plant for each of the nine distribution regions currently experiencing electricity deficits was selected. The selected embedded generations are shown in Fig. 4. They are as follows: 4717 MW solar power plant in Sokoto State, 1671 MW wind power plant in Katsina State, 938 MW hydro power plant in Taraba State, 574 MW hydro power plant in Ogun State, 125 MW hydro power plant in Kogi State,

2031 MW hydro power plant in Benue State, 625 MW natural gas power plant in Delta State, 1135 MW hydro power plant in Anambra State, and 1521 MW hydro power plant in Cross River State. The embedded power stations were chosen based on current existing generation power projects in the country, with high preference to renewable energy sources.

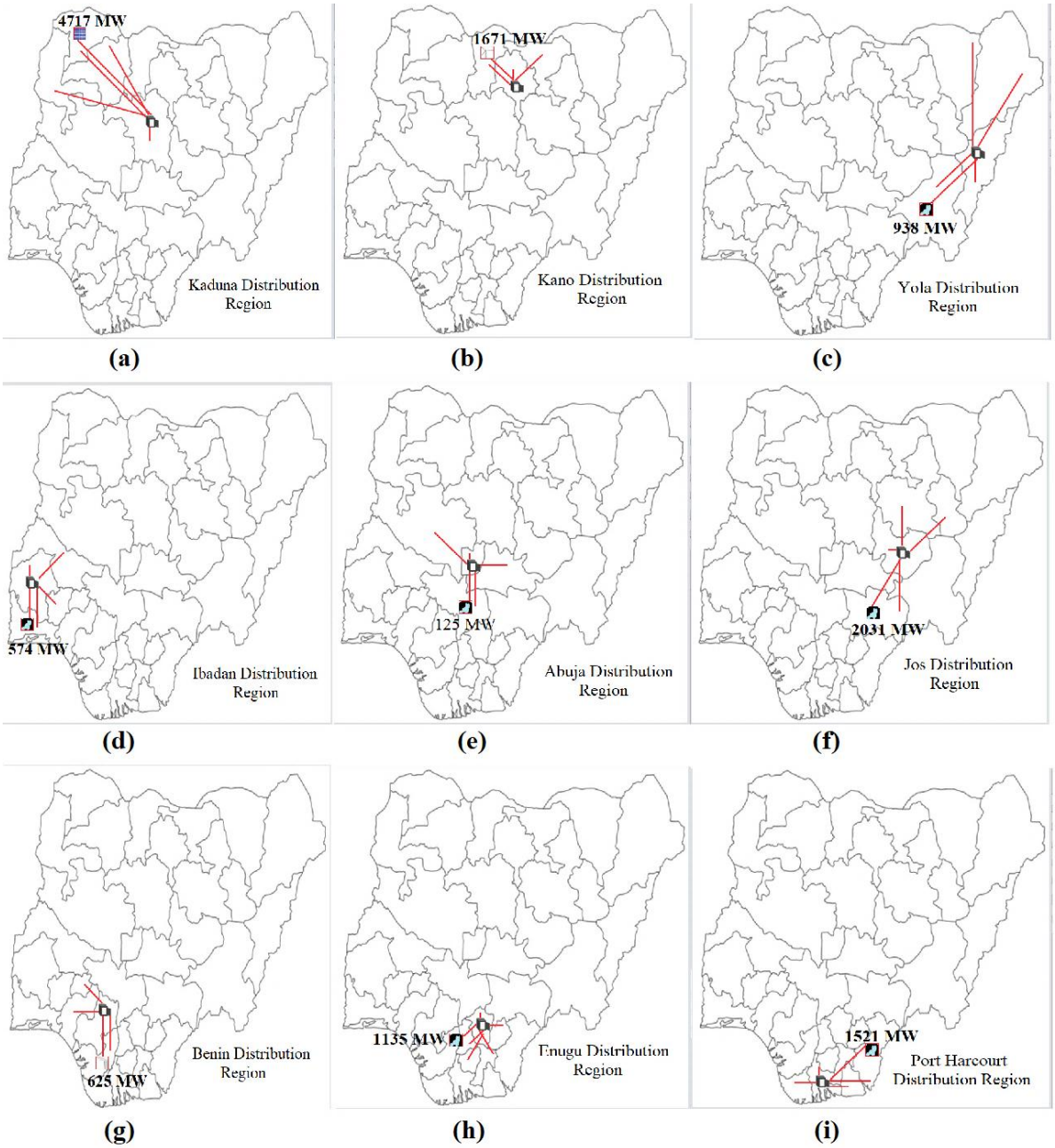

Figure 4: *Embedded Generation for 9 distribution regions in Nigeria (a) 4717 MW Solar Power Plant (b) 1671 MW Wind Power Plant (c) 938 MW Hydro Power Plant (d) 574 MW Hydro Power Plant (e) 125 MW Hydro Power Plant (f) 2031 MW Hydro Power Plant (g) 625 MW Natural Gas Power Plant (h) 1135 MW Hydro Power Plant (i) 1521 MW Hydro Power Plant.*

DISCUSSION

The seven types of generating power plants were ranked in terms of their eco-friendliness, cost, and operation efficiency. Where present, hydro power plants were given first priority, as they are the lowest levelized price of electricity compared to all major renewable energy and fossil fuel sources. They also have a fast response time to load fluctuations. Hydropower dams with large reservoir storage can be used to store energy over time (days, weeks, months, or years depending on reservoir size). Solar power plants were ranked second because they are less

costly than Wind power plants, which ranked third. Natural Gas power plants were ranked fourth, oil power plants fifth, coal power plants sixth, and finally, nuclear power plants seventh. Natural gas power plants were preferred over oil powered plants because of a greater capacity output. Both natural gas power plants and oil power plants were placed ahead of coal power plants because the nation already has these types of plants currently running and so it would be easier to build and install such plants. Nuclear power plants were ranked seventh because of the exorbitant costs and the radioactive wastes associated with this type of generating station.

For the Abuja Distribution Region, the Federal Government already has plans to build a 750 W hydro power plant in Lokoja, Kogi State, as well as the 700 MW Zungeru hydro plants in Niger State [13]. While the region has the potential to also build a wind, coal or nuclear power plant, either the Lokoja or Zungeru hydro power plant already under construction will meet the power generational need of 125 MW to address the electricity deficit the region is currently experiencing. It is therefore recommended that the Federal Government focus on the completion of either one of these two power plants to address the power shortage in this distribution region.

For the Benin Distribution Region, Natural Gas power plant was selected over oil power plant and coal power plant. The region currently has 8 natural gas power stations that are supplying electricity to the national grid [1]. These are Azura, Ihovbor, Okpai, Omotosho I, Omotosho II, Sapele, Sapele II, and Delta stations. Of these 8, only Azura and Delta are operating with a generation efficiency of over 75%. Therefore, instead of constructing and installing a 9th natural gas power station in this distribution region, it is recommended that the Federal Government boost the generation efficiency of one of the other 6 natural gas power plants currently serving the country (Ihovbor, Okpai, Omotosho I, Omotosho II, Sapele, and Sapele II) to obtain the additional 625 MW needed to ensure 24 hours of electricity supply in this region. Upgrading an existing natural gas power plant is also preferable and cheaper than installing a new coal power plant in Delta State for this distribution region.

For the Enugu Distribution Region, a 1135 MW hydro power plant is required to address the electricity shortage. There is currently a 1,050 MW Onitsha hydro power project for Anambra state that may prove suitable to improve the electricity supply to the region. The generation capacity of this project simply needs to be increased by 85 MW, and it is therefore recommended that the Federal Government expend its resources in completing this hydro plant. This distribution region is also rich in coal reserves, and a 900 MW coal fired plant can be considered for embedded generation in this region if the Federal Government seeks to expand and diversify the sources of electricity being utilized by the country. It is well known that the coal reserves can support coal-fired plants with total capacity between 15,000 - 20,000 MW [13].

For the Ibadan Distribution Region, only two states (Ogun state and Oyo State) were identified as having sufficient capability to possess an embedded generation plant, and this was in the form of a hydro power plant. However, the required capacity of the hydro power plant needed to address the region's electricity deficit is 574 MW. Unfortunately, bankable feasibility studies on the dams in this region so far show only the capability for small hydro power plants, such as the Oyan hydro plant (10 MW) and the Ikere George hydro plant (6 MW), which are grossly inadequate to meet the electricity demand of the region [14]. There are no known Federal Government power plant projects for this region that would address the current electricity shortage. The states that make up this distribution region do not possess either deposits of coal reserves, natural gas or crude oil. At this point, the region may have to depend on increased allotment from the national grid to address its power deficit, or explore the possibility of receiving additional electricity from a neighbouring distribution region, such as the Abuja Distribution region which has two ongoing Federal Government power projects that will supply excess electricity to its region.

For the Jos Distribution Region, a 2031 MW hydro power plant will be sufficient to take care of the electricity deficit. This distribution region also has the capacity to possess wind, solar and coal power plants. The 1,020 MW Makurdi hydro power plant project in Benue State should be given priority by the Federal Government to address the region's deficit. However, this project will require a hundred percent increase in the plant capacity if it is to ensure the supply of 24 hours of electricity to the region. If an increase in the planned Makurdi hydro power plant is not feasible, then an additional embedded generation unit may also be considered, especially if the Government is prepared to revitalize the country's coal mining industry.

For the Kaduna Distribution region, hydro, solar and wind power plants were considered feasible. However, the Federal Government hydro power plant projects in this region are small hydro power plants, such as the 40 MW Itisi project in Kaduna, and the 3 MW Bakalori project in Zamfara. These will not be capable of meeting the 2,877 MW hydro plant capacity required by the region to receive 24 hours

of electricity, and this region does not possess rivers, waterfalls and streams with high hydropower potential. It is therefore recommended that the Federal Government invest in the construction and development of a 4,717 MW solar power plant in Sokoto state to address the region's power deficit. Already the Nigerian Government has commissioned a 60 kilowatts (KW) grid connected solar power plant in Torankawa community of Sokoto state worth N146 million [18]. The capacity of the commissioned solar power plant needs to be increased to 4,717 MW.

For the Kano Distribution region, the hydro power potential is for small hydro plant projects, such as the 7.5 MW Challawa project in Kano, the 10 MW Tiga project in Kano, the 4 MW Jibia project in Katsina, and the 1 MW Zobe project in Katsina. They will not be able to meet the 1,172 MW hydro plant capacity required to ensure 24 hours of electricity for the region. A 10 MW wind farm has already been built in Katsina State [19], and as such, this region has the capability and expertise required to build a wind power plant. Because of this, it is recommended that the Federal Government invest in the expansion of the wind farm capacity to obtain the 4,104 MW needed to address the region's power deficit. This will help to diversify Nigeria's energy mix, boost electricity generation, and utilise the vast wind resources in the north of the country.

The Port Harcourt Distribution Region requires a 1521 MW hydro power plant to overcome its electricity deficit. Fortunately, the 730 MW Ikom hydro project in Cross River by the Federal Government will assist in rectifying the electricity problem. If the generation capacity of the Ikom project cannot be increased to 1,521 MW, it is recommended that the Federal Government should then improve the operational efficiencies of the 9 existing on-grid natural gas power plants in the region (Afam IV-V, Afam VI, ASCO, Gbarain, Ibom, Odukpani, Omoku, Rivers, and Trans-Amadi power plants). Of these 9, only Rivers and Omoku are operating with a generation efficiency of over 75%. ASCO and Afam IV-V currently have the lowest operational efficiency among the 9 plants and more emphasis should be placed on them. The ASCO power plant does not produce any energy for the national grid presently. It is more economically viable to improve the power generation of ASCO and Afan IV-V than to build a new natural gas power plant for this distribution region.

Finally, the Yola Distribution Region requires a 938 MW hydro power plant to be able to supply its region with 24 hours of electricity. Thankfully, the 3, 050 MW Mambilla hydro power project in Taraba State readily addresses this problem. It is therefore recommended that the Federal Government should ensure the completion of the Mambilla hydro power project as swiftly as possible.

In summary, in order to ensure 24 hours of electricity to every distribution region in the country, the Federal Government of Nigeria requires the following embedded generation units: 4717 MW solar power plant in Sokoto State, 1671 MW wind power plant in Katsina State, 938 MW hydro power plant in Taraba State, 574 MW hydro power plant in Ogun State, 125 MW hydro power plant in Kogi State, 2031 MW hydro power plant in Benue State, 625 MW natural gas power plant in Delta State, 1135 MW hydro power plant in Anambra State, and 1521 MW hydro power plant. in Cross River State. In order to accomplish this, it is recommended that the Federal Government complete the following power plant projects already in progress: 750 MW Lokoja Project, 1050 MW Onitsha hydro project, 1020 MW Markurdi hydro project, 730 MW Ikom hydro project, and the 3050 MW Mambilla hydro project. The Government also needs to improve the operational efficiencies of the on-grid Sapele, Sapele II, ASCO and Afam IV-V natural gas power plants, increase the capacity of the commissioned solar power plant in Sokoto State to 4717 MW, and increase the capacity of the Katsina wind farm to 4104 MW. These steps will ensure that every region in Nigeria experiences 24 hours of electricity every single day.

CONCLUSION

The power generation system in Nigeria currently consists of 3 hydro power stations in the North (Niger State) and 20 natural gas power stations in the south (Lagos, Rivers, Abia, Edo, Bayelsa, Kogi, Akwa Ibom, Cross River, Delta, Ogun, and Ondo States). Their combined electricity generation for October 16, 2019 was 80,249.18MWH or 3,343.72 MWH/H, which is well below the electricity demand for the country, leading to power outages across the nation. To rectify this problem, the paper proposes embedded or distributed power generation units that are proximal to the electricity distribution networks in the country. In order to ensure 24 hours of electricity for the 11 distribution networks in Nigeria, the country requires a 4717 MW solar power plant in Sokoto State, 1671 MW wind power plant in Katsina State, 938 MW hydro power plant in Taraba State, 574 MW hydro power plant in Ogun State, 125 MW hydro power plant in Kogi State, 2031 MW hydro power plant in Benue State, 625 MW natural gas power plant in Delta State, 1135 MW hydro power plant in Anambra State, and 1521 MW hydro power plant in Cross River State. It is recommended that the Federal

Government complete the following power plant projects already in progress: 750 MW Lokoja Project, 1050 MW Onitsha hydro project, 1020 MW Markurdi hydro project, 730 MW Ikom hydro project, and the 3050 MW Mambilla hydro project. The Government should improve the operational efficiencies of the on-grid Sapele, Sapele II, ASCO and Afam IV-V natural gas power plants and increase the capacity of the commissioned solar power plant in Sokoto State to 4717 MW and the Katsina wind farm to 4104 MW.

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