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Improving Power Supply in Nigeria: Embedded Mini-Hydro Power Generation

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ABSTRACT:
The public power supply in Nigeria had been abysmally low and has been attributed to the poor economic development of the country. Based on the observed poor power supply, it was found that the centralized public power system via the national grid system has introduced constraints and thus, negatively impacting on the power sector. This work has sought to provide solutions to the negative impact of the national grid system by the introduction of embedded power generation within DISCO franchise areas while not running afoul of the provisions of the EPSRA 2005. The franchise area of interest to achieve the objectives of the study was the Enugu DISCO. Major considerations of the energy resource selected were availability and sustainability. The mini-hydro dam system was selected data obtained from the Federal Hydrological Centre for the Imo River and an analysis carried out using a 15m head and the Fulton turbine. Results from the analysis show that the Umuahia city, within the Enugu DISCO, could be satisfied with the analysed additional 18.4MW of electricity from the mini-hydro dam proposed in this work. In the course of this work, it was observed that large swathes of the territory within this region are neither connected to the grid nor have access to electric power. The research and development of several mini hydro plants could bring the much needed succour to the unconnected areas. In view of the findings, it was recommended that the mini-hydro power generation and off-grid power should be implemented across Nigeria to significantly boost power generation, supply and improve access to public electricity.

I. INTRODUCTION

Over the past decade, the Federal Government of Nigeria has attempted to forge a new policy direction for the power sector. The overtly centralized power generation, transmission and generation was restructured into districts and privatized to a large extent. The sector was broken up into generation, transmission and distribution.

The generation subsector consists of plants of different energy mixes. There are gas-fired plants, steam turbines and hydroelectric dams. These three types make up the totality of public power generated in Nigeria. The power generated is injected into the transmission network and distributed to regional distributors; the DISCOs.

The DISCOs 100% depend on the power allocation of the Transmission Company of Nigeria (TCN). Each DISCO must make do with the power allocated to it and must distribute it as such. The data available shows that the power allocated to each DISCO is inadequate as it does not meet the energy demand of the customers of each DISCO. Some DISCOs are unable to satisfy up to 10% of the Energy Demand of its customers. As a result of this acute shortfall, there is the need to improve power supply through sundry means.

The policy of the federal government however, only permits DISCOs to distribute power but not to generate same. Yet, the DISCOs must seek ways and means to improve power supply in their franchise areas without running afoul of the law. This research seeks to investigate methods of improving the regional power availability and reliability via embedded generation.

Recall that the energy mix of Nigeria is significantly biased towards gas-fired turbines. Gas turbines, nuclear power and large dams have high environmental footprints and huge capital costs. This work seeks to investigate the use of renewable energy resources as the means of providing power in the embedded power generation. The renewable energy of choice in this work, is the mini-hydro system.

The mini-hydro system, when carefully designed and with proper location selection, has a lower environmental footprint, zero carbon emission, lower capital cost and yet, has the capacity to vastly improve power supply within a regional grid.

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With the advantages of the mini-grid in mind, the city of Umuahia within the franchise area of the Enugu DISCO, was selected as the load centre of choice for the research study. The choice of Umuahia has been selected due to the following reasons:

1. There is shortage of power supply to the load centres
2. There is availability of rivers and streams in the localities
3. The rivers and streams selected are "deep valley" and "high velocity" types suitable for the technology of choice.

The work shall seek to situate the significance of the mini-hydro power generation to these two cities and the injection of the power into the regional grid in this embedded power generation philosophy. The mini-hydro generation shall be of a third party type with generated power dedicated to specific load centres as mentioned above.

The power available for distribution to the DISCOs is inadequate to meet the energy demands of the various regional customers. The Enugu DISCO among others, suffers acute power shortages due to the aforementioned problem. The cost, environmental impactand policy implications have left very little room for the DISCOs to effectively provide the much needed power. There is the need to improve power supply via embedded generation that do not run afoul of government policy or the carbon emission requirements of the international environmental protection agencies.

From the foregoing:

1. There is the need for embedded power within regional grids of the Enugu DISCO
2. The embedded power must be based on renewable energy resource
3. The renewable energy resource of choice is the hydroelectric dam
4. The mini-hydro is selected for its low cost, policy-friendly and low environmental footprint
5. The mini-hydro shall be location-specific.

The Federal Government of Nigeria has strived to improve the power supply situation in Nigeria over the past decade. Policies have been put in place to build independent power plants (IPP) in strategic locations across the country. Billions of dollars have been expended to carry out this with varying degrees of success.

Nigeria is a gas-rich country. Gas is readily abundant and relatively cheap. As a result of this, the comparative advantage of the country in gas production has greatly informed the choice of gas to power the IPPs being constructed across the country. The IPPs are gas-fired (either as Single Cycle Gas Turbines or Combined Cycle Gas Turbines).

Despite the policy of the government to massively construct IPPs and the recent deconstruction of a monolithic distribution system into regional grids (DISCOs), the power supply to the various regional customers is largely inadequate. The DISCOs must explore avenues to improve the power supply to the customers; to close the huge gap in the energy demanded and energy available for supply.

This work is significant in that it shall showcase how to improve the energy supply situation to specific localities within a regional grid, using renewable energy resources for embedded generation.

II. LITERATURE REVIEW

The theoretical framework of this work is to ascertain the improvement of electricity by employing renewable energy resources as embedded (distributed) power generation within regional grids. The framework of this work is to ascertain the impact of the mini-hydro dams as a renewable energy, to generate distributed power to specific localities within a regional grid, and ultimately improving power supply within the Regional Grid.

A grid system is such in which the power generation facilities are interconnected via a transmission network, conveying electrical power to various load centres. Woodall (2012) posits that the interconnectivity between the generation, transmission and the distribution in the electric power system is held together by the transmission backbone. Woodall posits that the grid electrical power system is a single, and most expansive live machine where the Adequacy & Reliability must be guaranteed.

Guaranteeing the reliability & adequacy of a power grid is greatly impacted by the system operator. The system operator of a power grid is the entity that ensures the balance between the generation, transmission & the distribution in an electrical grid system. The system operator strikes a balance between the power demanded and the power supplied. Nnaji (2012) describes the System Operator as the entity that combines the operational efficiency of the power grid by the management of the grid.

The grid system could be national or regional. The national grid (as done in Nigeria) combines all the generating companies (GENCOs), the distribution companies (DISCOs) and the transmission company (TCN) into a single system, all managed by a system operator. In India, there is the national grid system, and a series of regional grids. The regional grids have their control areas which are consists of all aspects of generation, transmission and distribution. The regional grids have individual system operators that ensure the balance of power demand and supply, ensure reliability & adequacy, yet are connected to the national grid on a different level. Woodall (2012) describes electrical grids as "interconnected regional systems".

Galli (2013) wrote extensively about the regional grid system in North America. There are three major interconnections in North America, eight (8) grid regions and 135 Balancing Authorities. This robust method of regional grid systems gives a more reliable system reliability at the regional and national levels.

There is a system operator in any grid systems whether at the national or regional level. In regional grids, there is the possibility of embedded power generation of distributed power generation. Embedded generation is the term used to describe the process of generating electricity at a specific location and then connecting that supply into the electricity network.Embedded generation is otherwise referred to as distributed Generation (Cipcigan, 2007). The philosophy of this concept is that power is generated for a specific locality, but connected to the grid and thus, subsumed in the grid system. There are different technologies available to generate power within a regional grid system. It is important to note here that embedded generation provides 52% of the power requirements in Europe. Jenkins (1996) wrote extensively on the embedded power generation and power requirements for specific localities.

There are several advantages of Embedded Generation. Some are listed below:

1. Reduced transmission losses
2. Reduced construction costs
3. Reduced environmental footprints
4. Supply & demand are more easily matched
5. Operational reliability is more easily guaranteed.

S. Beula (2014) discussed the hybrid systems for embedded power generation. Here, it was discussed that the embedded power is mainly based on renewable energy systems. The embedded power plants are mainly based on the solar power, wind power and mini hydro power generating systems.

The embedded power models have requirements of mainly less than 50MW of electricity. Such power requirements are easily provided for using the renewable energy resources. The renewable energy plants have the following characteristics:

1. Easy to construct
2. Lower capital cost
3. Less environmental footprints
4. Easy to integrate and manage.

For the purpose of this work, the renewable energy resource of choice for the embedded power plant is the Hydro System; the Mini-hydro System. The choice of city is Umuahia which is within the Enugu DISCO Control Area (or Enugu Regional Grid).

Water has been employed for motive power for thousands of years. In the past two centuries, water has played a major role in the generation of electricity. Hayes (2009) and Slaheddine (2013) wrote extensively about dams for agriculture, water storage and the use of dams in the generation of electricity.

The construction of hydroelectric dams for power generation took hold in the 19th century with the Fox River Dam, Appleton,Winsconsin on September 30, 1882. There have been hundreds of hydroelectric dams built since 1882; some giant ones like the Three Gorges Dam in China, the Tennessee Valley Authority in the USA, the Ithaca Dam in Brazil, and numerous others.Tisley (1983) wrote extensively about major dam developments across America.

Hydroelectric dams could be classified as follows:

1. Large dams (100MW and above)
2. Medium dams (20MW to 100MW)
3. Mini dams (less than 20MW).

The capital outlay in the construction of large dams is extensive. There is alwaysthe challenge of cost of construction. Awojobi (2016) wrote extensively on the costs and how to mitigate these costs with different forecasting techniques. Despite these, the mini-dams still outperform the large dams as regards costs.

The engineering complexity, environmental footprints, operational costs and several other factors have led to less emphasis on the construction of the large dams. The cost per MW is much higher than that of the medium and large dams. In recent times, the Turbine Technology has been made more efficient such that such large dams are hardly required. For the purpose of this work, the new technology for hydropower generation shall be employed. The recent turbine technology is most suited for mini dams.

Hydroelectric Power generation brought about a revolution in the way of life and standard of living of man. It led to economic boom for the cities and countries that adopted this for power generation. Yet, the large dam has its own attendant problems as regards huge environmental footprints, ecological changes, high capital cost and high cost per MW. Paucity of funds, government and international policies, and several other factors, have led to the search of alternative sources of energy. There is the need to explore the mini-hydro system as a replacement for the large dams especially in embedded power generation systems.

The mini hydro plants have been around for a few decades. Adhau (2012) explored the Indian experience whereby existing earth dams for irrigation were modified to include power generation to serve the immediate power needs of the localities. Pundir (2014) described a full-scale study of the technical feasibility study for power generation using the mini hydro system.

Mini hydro have the potential to generate from a few kW to 20mW or more.

The unique characteristics if the mini hydro systems are:

1. Lower environmental footprints
2. Lower capital costs
3. Lower operational costs
4. Easy maintenance.

Technological advances in hydroelectric power generation have given rise to the mini hydro depending more on high flow velocity of the water over a small head (height). The large dams are built more for slow moving water over a large head. Large dams depend on a huge water reservoir behind the dam, with a greater emphasis on the potential energy of the water due to height, the mini hydro require a small head and a large kinetic energy. As a result of these fundamental differences, the turbine designsare very different. The mini hydro system, as a renewable energy resource, is making inroads into the power generation especially in the embedded power generation system.

Siraj (2012) and Ptasinki (2015) discussed extensively about renewable energy resources. There is the change in philosophy of power generation towards the use of renewable energy resources.

In developing countries, the wind, solar and mini-hydro have been the most sought renewable energy resources especially in the provision of power to the rural areas. Adhau (2012) discussed the provision of electricity to rural India using the mini-hydro system. Ardehali (2006) discussed the opportunities for rural development employing renewable energy resources for the provision of power in Iran.

The renewable energy resource of choice for power generation in a specific location depends on the following:

1. Easy access
2. Resource data available
3. Technical availability & capability
4. Policy support
5. Costs.

The main thrust of this work is the mini-hydro system as a renewable energy resource for embedded power generation. As a result of this, this work shall deliberate more on mini hydro systems for embedded generation.

III. METHODOLOGY

1. Water velocity
2. Draught
3. Width of Channel
4. Depth of Valley
5. Flow Distribution Curve
6. Power Distribution Curve
7. Turbine Selection Parameter

These are the required parameters design the mini hydro station for maximum output. The water velocity helps in the choice of the turbine. The water depth helps to determine the sizing of the turbine and the turbine housing/water breaker (dam), the width of the channel helps to determine the overall number of turbines to be used. The depth of valley helps determine the height of the water breaker.

Data could be extended to provide the length of the channel. With greater length, a cascade mini hydro system could be put in place. In this cascade method, two or more mini hydro plants could be placed in series with one feeding the next downstream thereby increasing the output of the cascade system. In this method, the output of a plant could be increased by a calculated factor and thus greatly increasing the capacity of the system.

In this work, the mini hydro embedded generation has been recommended as a means of improving power generation to Umuahia City, and ultimately improving power supply within the Enugu Electricity Distribution Company.

The EEDC is DISCO within the Nigerian national electricity grid system. It is not within its own regional grid but its operations could be likened to that of a regional grid sub operator. In this work, we shall attempt to situate the mini hydro embedded generation near load centres

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within the Enugu DISCO franchise area. We must however, have some knowledge of the power requirement, and shortfall to the Enugu DISCO. See the data below:

Table 3.6: Table showing the average transmission & distribution Electricity Transmission & Distribution Data to DISCOS (2017)

S/N	DISCO	AVERAGE POWER TRANSMITTED (MW)	% TRANSMISSION	PEAK LOAD DEMAND (EW)	LOSSES (%)
1	ABUJA	284.35	11.40	835	35
2	BENIN	235.60	9.45	100	21
3	EKO	271.99	10.91	1105	18
4	ENUGU	222.53	8.92	1017	6
5	IBADAN	329.44	13.21	1193	8
6	IKEJA	370.89	14.87	1335	18
7	JOS	135.99	5.45	507	22
8	KADUNA	197.81	7.93	520	25
9	KANO	197.81	7.93	596	40
10	PORT HARCOURT	160.72	6.45	773	-
11	YOLA	86.54	3.47	176	22
		2,493.69	**100**	**8,157**	

From the table above, the shortfall of the measured demand across Nigeria is 8,157MW of electricity. This figure excludes the suppressed demand estimated at about 8,000MW which represents the unconnected potential customers.

The Enugu DISCO (the area of interest) for this work has a shortfall of 1,017MW. At an average energy supply of 222.53MW, the Enugu DISCO is grossly undersupplied.

The EEDC sources power from the national grid and has a shortfall of about 75% of power demand available for distribution in the Enugu franchise area. None of these cities is supplied its actual demand. The average demand in Umuahia is 60MW but is supplied less than 20MW. The prospects of the supply from TCN increasing to satisfy the regional demand is not immediately feasible. There is the need for the EEDC to introduce embedded power generation systems (distributed generation) targeted to specific cities. The mini hydro plants come into play.

In line with the philosophy of the embedded mini hydro plant as a renewable energy source for distributed generation dedicated to Umuahia.

The river of choice for the establishment of the mini hydro plant here is the Imo River.

The Imo River is a high volume, high velocity river with source around Okigwe. It runs through a valley about 10km west of Umuahia. There is sufficient hydrological data for this river. All the data obtained show good prospects for the establishment of the mini-hydro plant.

See the tables below.

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Table 2: Table showing Hydrological Data Monitoring over a 10-year period of the Imo River

S/n	Year	Annual maximum stage (h) at Ndimoko (m)	Annual maximum discharge (Q) at Ndimoko (m^3/s)	Annual maximum stage (h) at Umuna (m)	Annual maximum discharge (Q) at Umuna (m^3/s)	Annual maximum stage (h) at Umuopara (m)	Annual maximum discharge (Q) at Umuopara (m^3/s)	Annual maximum stage (h) at Obigbo (m)	Annual maximu m discharg e (Q) at Obigbo (m^3/s)
1	1978	3.02	25.00	4.48	77.50	5.66	270.00	2.06	246.00
2	1979	2.59	18.20	4.59	80.00	4.54	158.40	1.97	232.00
3	1080	3.30	27.50	4.84	96.00	3.95	118.00	2.14	261.50
4	1981	3.14	24.40	3.97	62.40	6.23	258.28	1.90	220.00
5	1982	3.16	18.90	1.99	17.00	4.75	187.50	1.91	240.80
6	1983	3.14	24.50	4.62	81.60	5.53	223.00	2.23	263.89
7	1984	3.00	22.84	4.18	68.40	3.22	126.20	1.54	176.40
8	1985	2.95	22.28	4.71	84.60	4.83	194.40	2.29	286.20
9	1986	2.79	20.49	4.87	89.10	3.00	115.00	1.75	200.00
10	1987	3.56	29.51	4.63	80.40	5.19	223.20	1.92	223.20
11	1988	3.52	29.02	4.89	89.70	1.32	42.85	2.40	306.80

Source: The International Journal of Engineering & Sciences, Vol 2, Issue 5, 2013

Table 3: Table showing the Stream Flow Model of the Imo River at Designated Points

S/n	Streamflow gauging station	Streamflow Model⁺ $Q = k\,(h)^b$	Model Performance Indicator*
1	Ndimoko	$Q = 4.423\ h^{1.495}$	$r^2 = 0.908$ $r = 0.953$ $S_{Q.h} = 1.82$
2	Umuna	$Q = 4.702\ h^{1.868}$	$r^2 = 0.997$ $r = 0.998$ $S_{Q.h} = 2.19$
3	Umuopara	$Q = 30.02h^{1.177}$	$r^2 = 0.959$ $r = 0.979$ $S_{Q.h} = 17.40$
4	Obigbo	$Q = 102.4\ h^{1.224}$	$r^2 = 0.969$ $r = 0.984$ $S_{Q.h} = 6.41$

⁺ Annual maximum stage is given in meter (m) and annual maximum discharge in cubic meter per second (m^3/s)
* Model Performance Indicator
r^2 = Coefficient of determination
r = Coefficient of correlation
$S_{Q.h}$ = Standard error of estimate of discharge (Q) on stage (h)

Source: The International Journal of Engineering & Sciences, Vol 2, Issue 5, 2013

With the data available, the Imo River has the capacity to generate over 20MW for the city of Umuahia under an Embedded Power Generation System.

The turbines to be selected shall be tailored to meet the hydrological data obtained for the Imo River. The turbine selection, the height of valley and the width of the river at the point of interest shall determine the sizing of a single array of the turbine generators.

Actual design is beyond the scope of this work. The aim of the work is to ascertain the technical possibility of establishing a mini hydro plant on the Imo River for distributed power generation for Umuahia in the order of 10MW of electric power.

The turbine selection is based on the following parameters:

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1. The height of the dam: this is determined by the hydrological and location properties of the river. The philosophy of this mini hydro plant is to have a small head so as to have very minimal environmental footprint
2. Volumetric Flow: The volume flowrate must be determined. From the hydrological properties given, the volume flowrate is 5.0 m^3/s.

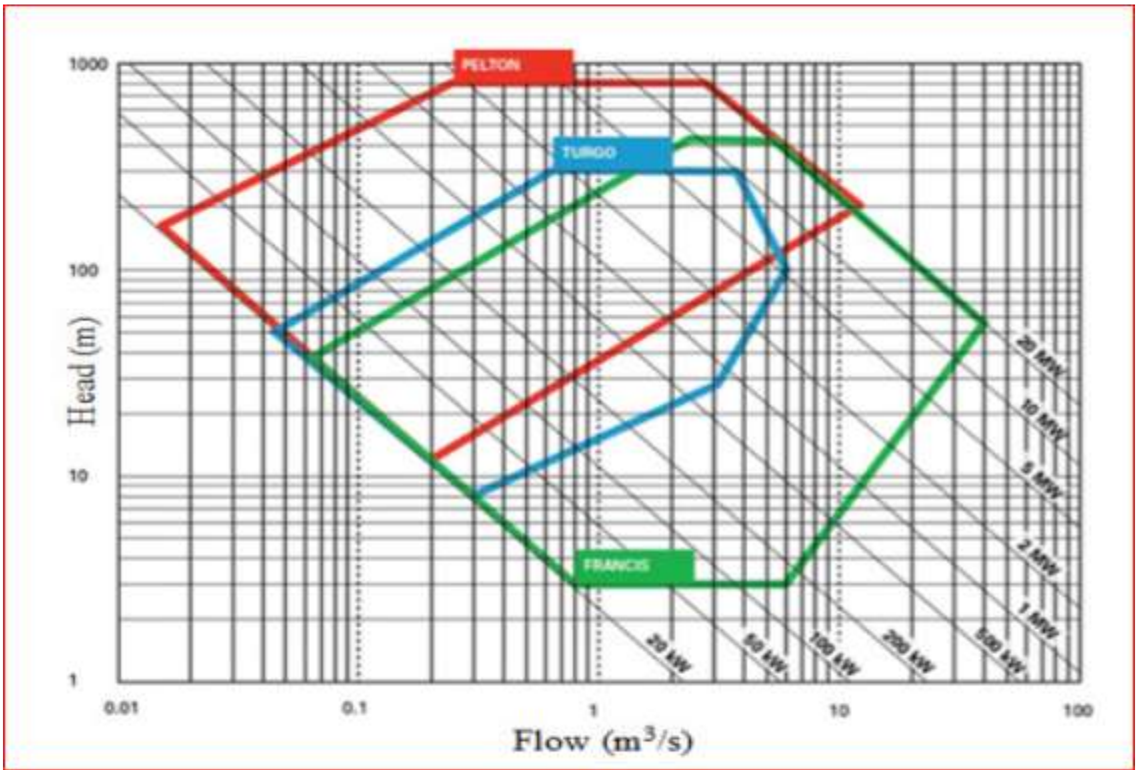
These two parameters are the key components for turbines selection. The turbines with the highest extractive and output efficiencies are chosen. See the Turbine selection chart below.

From the data obtained on site, the following:

1. Maximum height of dam = 15m
2. Hydrological Volumetric Flow of Lead Water = $10m^3/s$ (averaged flow water)

Turbine selection Chart for the given parameters shows the turbine to be selected as 1MW.

Turbine Selection Chart



Source: Nigeria Journal of Technology, Vol 34, Number 3, July 2015

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IV. RECOMMENDATIONS & DISCUSSIONS

5.1 Table of Results

S/N	Descriptive Parameter	Size
1	Width of River	14m
2	Valley Depth	16.5m
3	Draught	5m
4	Height of Dam	15m
5	Diameter of Penstock	2m
6	Turbines in Parallel	5
7	Turbines per Penstock	4
8	Total Number of turbines in a Cascade	20
9	Length of Penstock	24m
10	Angle of Penstock	15degrees
11	Volume Flowrate	$10m^3/s$
12	Number of Sluice Gates	2
13	Output per Turbine	1MW
14	Total Calculated Output of a Cascade	20MW
15	Turbine Efficiency	0.92
16	Expected Output	18.4MW

From the table above, it is observed that the height of the dam at 14m gives a safety of 2.5m below level ground. The choice of the point of dam placement (deep valley area around Obowo Local Government in Imo State) is to reduce the environmental footprint of a large reservoir behind the dam. The dammed river is calculated to back-off behind the dam but within the valley. The presence of the sluice gates is to control the water level such that it does not go beyond the 2.5m safety mark to cover the level ground. With this design philosophy in mind, the reservoir volume shall be small but sufficient to power the turbines as designed.

The choice of placing four (4) turbines in a Penstock is to extract as much potential and kinetic energies from the flowing water as much as possible. The hydrodynamic losses from one turbine to the other have not been calculated though, but a simulation of this could be carried out during detailed engineering. It is expected that the lead turbine would have greater efficiency of energy extraction than the last one in the penstock.

The placement of he turbines in series and in parallel is to maximise the utility of the dam without compromising the integrity. Design consideration for thicker bases shall be considered in this case. The necessity of space optimisation is that the valley height of the Imo River reduces tremendously as it approaches the Atlantic Ocean. The river valley is deepest between Okigwe and Owerrinta in Imo State (about 100km). The distance of the plant to the Umuahia Injection Station however was considered.

The design choice of the 20 degrees angle of the penstock is to increase the volume flowrate of the water as it flows into the turbines. This angle is a trade-off between the height of water which diminishes sufficiently as it approaches the last turbine in the penstock. Operational efficiency could make up for this during actual operations.

The choice of the turbine is determined by the flow parameters and the height of the dam. The maximum plant output is 18.4MW.

V. CONCLUDING REMARKS

This work has been carried out with the philosophy of embedded mini hydro plant as a renewable energy resource to improve power within the Enugu DISCO Area. Umuahia was chosen as the city of interest due to its proximity to the Imo River.

From the calculations and observations in this work, it is possible to construct a mini-hydro power plant within the Enugu DISCO on the Imo River to provide targeted generation to specific cities.

It was observed that possible locations for the construction of the mini hydro extend along this river up to a 100km. It is possible to have a cascade dam type of several dams in series over this stretch of river probably every 20km. With the cascade dams, it would be possible to increase power availability to the Enugu DISCO by at least 60MW (equivalent to three cascade dams of the specifications of this work).

The major significance of this dam design is the low environmental footprint and the

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renewable energy appeal. The low cost of the dam construction (14m height by 15m length by 15m width) is appealing. The cost per MW of construction is very low relative to the large dams with their attendant huge environmental footprints.

It is recommended that further work be carried out on this research. It is also recommended that the Enugu DISCO should commission a research to carry out Hydrological Data on all rivers and streams within their area of control so as to ascertain probable locations for the development of mini hydro plants in close proximity to injection points.

In the course of this work, it was observed that large swathes of the territory within this region are neither connected to the grid nor have access to electric power. The research and development of several mini hydro plants could bring the much needed succour to the unconnected areas. The several mini hydro plants thereof could be connected to the "regional". The possibilities of the development of the mini hydro embedded generation in this region are available. Extensive work should be carried out to harness this resource.

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