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# A Pricing Policy for a University- Based Smart Microgrid (Revised): A Case Study Of Federal University of Technology Owerri

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**Abstract:- Every Nigerian tertiary institution requires adequate power supply to operate effectively for its administrative, academic and miscellaneous functions. The challenge of insufficient power supply by utility generally remains a constant setback in these institutions. This consequently leads to a high dependence on alternative means of electricity generation most of which are usually more expensive than the supply from the public utility. The most common dependence is on diesel and petrol generators, while a few others attempt to go on renewables. Moreover, every institution also needs to break even on both productivity and finances after every academic session. Thus there is the need to strike a balance between the cost of power generated for a set of consumers, the cost of generation, and the profitability of alternative power generation. This research is concerned with using the load profile of the Federal University of Technology Owerri to develop a pricing policy for a microgrid network comprising two 500 kW solar farms, a 100kW microhydro plant and the already existing diesel generators. The method of direct cumulative computation was used with the data collected both during the current market surveys for the renewable components and the expected daily load usage curves. This policy will enable a consumer to schedule load usage and minimize energy wastage, determine when the university can expect returns on investment on alternative energy generation and enable the university develop a tariff system of operation where necessary.**

***Keywords:-*** *Pricing Policy, Renewable, Return on Investment, Optimization, Tariff.*

## I. INTRODUCTION

Electric power is generally termed the life blood of modern civilization. Similarly, every developed society cannot boast of civilization without good education, thus the importance of good education cannot be over-emphasized as relates community development. The average Nigerian tertiary institution is saddled with the responsibility of developing students academically, as well as performing other tasks ranging from administration, welfare (including staff andstudent accommodation, feeding, leisure), research, etc. Thusthere is need for adequate power supply in order to execute these roles efficiently.

The Nigerian electricity utility system over the years has proved insufficient to handle the daily energy requirements of most tertiary institutions thereby prompting the need for alternative sources of electric energy, to supplement what obtains from the utility grid, to satisfy the most basic daily load requirements. The choice of alternative sources directly or indirectly impact the environment and economics of the tertiary institution under study.

The case study institution for this research is the Federal University of Technology Owerri,

## II. PROBLEM STATEMENT

The Federal University of Technology (FUTO) campus is presently connected to the national grid, but because of the unavailability of power supply almost throughout the year, there is a relatively high dependence on the backup diesel generators. This leads to very high annual expenditure on fuel and generator maintenance costs, as basic load demands have to be met for the smooth operation of University activities.

Designing a workable smart micro-grid was necessary be the first step to curbing energy wastage and properly dispatching required energy to consumer loads based on a load schedule algorithm. [1]

## III. RESEARCH OBJECTIVE

The main objective of the research is to develop a pricing template for the smart micro-grid earlier developed for the Federal University of Technology. Other objectives include:

- Determining the optimal operational cost
- Possible expectation on return on investment.
- Developing a tariff system assuming each building is financially responsible for their daily energy consumption.

## IV. FEATURES OF THE PRE-DESIGNED SMART MICRO-GRID

Two 500kW solar farms and one 100kW microhydro plant were proposed based on the daily load requirements of the university. The following are the features of the smart microgrid designed and the relevant information curbed for this work.

- Plant-side Energy management algorithm, based on the following parameters,
  - ✓ State of charge (SOC) of battery bank
  - ✓ Float voltage of battery bank
  - ✓ Power from the available plants
  - ✓ Maximum and minimum chargingcurrents

- ✓ Upper and lower limits for current and voltage during charging/discharging
- ✓ Priority-based load demands

- Consumer-side Energy management algorithm, which borders on
- ✓ Time of day
- ✓ Load priority
- ✓ Plant availability

- Load scheduling
- ✓ Sizing of the renewable energy plant components
- ✓ An architecture showing the interconnection of the plant components
- ✓ Sensitivity analysis to determine the optimal placement of the various renewable plants.

- Other relevant information required for this work include
- ✓ The diesel generator distribution across theuniversity.
- ✓ the cost of installing the individual renewable energy plants.
- ✓ The daily cost of public utility supply

## V. PLANT COMPONENTS

The proposed plants were sized to accommodate a functionally installed load of 1150kW in the day and 3.5MW at night and comprises the following:

### *A. The 500kVA Solar Farm*

The 500 kVA solar farms in the proposed design each consist of two wings of 1080 solar arrays. Each wing consists of four streams of 270 x 250W monocrystalline solar panels. Each stream of 270 panels is connected to give an output voltage of 48-96 volts corresponding with that of the respective PV inverter rating and the battery bank arrangement. Depending on the cost, PV inverters can be cascaded to feed the grid control inverter and the connected AC load. The specifications of each solar panel are shown in the Table 1.

Table 1: Solar Panel Specification [1]

| DESCRIPTION | RATING |
|---|---|
| Rated Maximum Power ($P_{Max}$) | 260 W |
| Open Circuit Voltage ($V_{OC}$) | 38.4 V |
| Rated Voltage ($V_{mpp}$) | 31.4 V |
| Short Circuit Current ($I_{SC}$) | 8.94A |
| Rated Current ($I_{mpp}$) | 8.37 A |
| Power Specification at STC | 1000W/m$^2$, 25°C |
| Application Class | Class A |

### *B. PV Inverter*

It is a wall-mounted transformer-less inverter with two maximum power point (MPP) trackers which converts the current of the PV array stream directly into grid compliant alternating current and feeds it into the grid and monitoring/ control system.

Table 2: PV Inverter specification [1]

| DESCRIPTION | RATING |
|---|---|
| Rated Maximum Power ($P_{AC}$) | 500kW |
| Rated AC output voltage ($V_{AC}$) | 220V |
| AC voltage output range ($V_{AC, Range}$) | 180V -280V |
| Current rating ($I_{AC, @220V}$) | 10.5 kA |
| Maximum rated current | 12.5 kA |
| Maximum Input DC Voltage | 750 V |
| Operating AC frequency ($f_{AC}$) | 50 Hz |
| cos Φ | 0.84 |
| Fuse Rating | 250 A |

### *C. Alternative AC Sources*

These will include the diesel generators and theproposed micro-hydro plant. The diesel generator distribution for the university main campus and hourly fuel consumption charts are shown in Table 3, Table 4 and Table 5 below.

Table 3: Diesel Generator Distribution in FUTO with marketvalue and installation cost

| LOCATION | CAPACITY | LOAD SERVED | Average Market +Installation Price |
|---|---|---|---|
| Senate Building | 500 kVA | Alone | N34.67 million |
| School of Agriculture & Agric. Technology | 500kVA | SAAT, SAAT annex, Biochemistry building, Center for Nuclear research. | N34.67 million |
| School of Health Technology | 35kVA | Alone | N7.5 million |
| **School of Science (SOSC)** | **500kVA** | **SOSC building, Physics building, Lab. Sciences building.** | **N34.67 million** |
| **CIS** | **500kVA** | **Workshop 2, Workshop 3, Mech. Engr. Workshop.** | **N34.67 million** |
| **Estate & Works** | **135kVA** | **Est & Works, Student Affairs Unit.** | **N11.25 million** |
| **GEJ Engineering Complex (SEET)** | **800kVA** | **SEET, ICT Building** | **N58.43 million** |
| **Hostels** | **800kVA** | **Hostel A-E** | **N58.43 million** |
| **Library** | **275kVA** | **Alone** | **N23.86 million** |
| **Petroleum Engineering Building (PET)** | **500kVA** | **Petr. & Chem. Eng. building** | **N34.67 million** |
| **NDDC Hostel** | **500kVA** | **NDDC hostel, Junior Staff quarters.** | **N34.67 million** |
| **1000 Capacity Lecture Theatre** | **100kVA** | **Alone** | **N9.2 million** |
| **FUTO Guest House** | **45kVA** | **Alone** | **N6.7 million** |
| **FUTO Consult** | **60kVA** | **Futo Consult, Health Center** | **N8.1 million** |
| **University Computer Center (UCC)** | **35kVA** | **UCC, Afrihub** | **N5.57 million** |
| **PTF Pumping Station** | **100kVA** | **Alone** | **N7.2 million** |

Table 4: Average Hourly consumption of diesel generators

| LOCATION | CAPACITY (PF=0.8) | LOAD SUPPLIED | FULL-LOAD CONSUMPTION PER HOUR (Liters); |
|---|---|---|---|
| **Senate Building** | **500 kVA** | **400kW** | **135.125** |
| **School of Agriculture & Agric. Tech.** | **500kVA** | **400kW** | **135.125** |
| **School of Health Technology** | **35kVA** | **28kW** | **13.06** |
| **School of Science (SOSC)** | **500kVA** | **400kW** | **135.125** |
| **CIS** | **500kVA** | **400 kW** | **135.125** |
| **Estate & Works** | **135kVA** | **108 kW** | **37.073** |
| **GEJ Engineering Complex (SEET)** | **800kVA** | **640kW** | **215.37** |
| **Hostels** | **800kVA** | **640 kW** | **215.37** |
| **Library** | **275kVA** | **220kW** | **75.51** |
| **Petroleum Engineering Building (PET)** | **500kVA** | **400kW** | **135.125** |
| **NDDC Hostel** | **500kVA** | **400kW** | **135.125** |
| **1000 Capacity Lecture Theatre** | **100kVA** | **80kW** | **28.01** |
| **FUTO Guest House** | **45kVA** | **36kW** | **15.9** |
| **FUTO Consult** | **60kVA** | **48kW** | **18.17** |
| **University Computer Center (UCC)** | **35kVA** | **28kW** | **13.06** |
| **PTF Pumping Station** | **100kVA** | **80kW** | **28.01** |

*D. The 100 kW micro hydro plant*

This can be harnessed from the existing Otammiri stream flowing through the university. Although previous studies have shown that the flow rate of the stream can barely support 70kW, recent damming technologies can enable us optimize this output for our proposed design. Fig 1 shows the estimated cost of installing Hydro power plants per kW. The plant under consideration is a micro-hydro which falls into the kW range of 10-100kW.

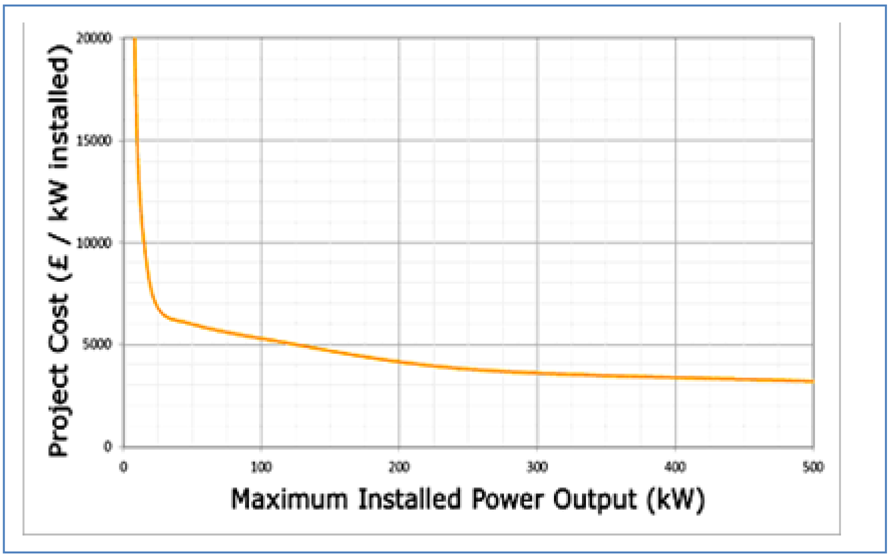

Fig 1: Estimated cost of installing Hydro power plants per kW [3].

*E. Monitoring And Control Components*

These comprise

- Battery inverters (islands): This inverter controls the electrical energy balance in an off-grid system, in a battery backup system, or in a system for increased self-consumption. It is wall mounted and uses batteries for the storage of energy. It is responsible for the seamless switching between the PV, alternative AC sources and the Battery bank, while maintaining full control on the charging of the battery bank. The AC output from the PV inverter feeds directly into the **$AC_1$** terminal of the island while alternative AC sources are fed into the **$AC_2$** slot. Some sensors and communication terminals with other islands also terminate here including an Ethernet link for online system monitoring.
- Cluster controller: It is the high performance communication hub for the micro grid which continuously collects all the data from the inverters on the system side, thereby keeping real-time information on the system status. It is equipped with terminations for sensors and other devices for remote monitoring.

It is a multi-functional energy efficient data logger which offers numerous options for displaying, archiving and processing data, even in networks with strict security regulations. In the event of an ERROR message, it is configured to inform the operator immediately by email or text message. It also has USB slots for memory drives to store the logged data in the event where there is no internet connection. Most of the sensors (solar radiation sensor, ambient temperature sensor, motion sensors, pressure sensors, key card sensors, etc) also feed into this device.

It can also be configured at the consumer end for monitoring and control. This can then communicate wirelessly with the controller at the plant end via wireless routers and repeaters.

- Remote Control/display:

This component displays parameters like the state of charge of the battery, indicates how much power is coming from the panels and whether the panels are charging the batteries while supplying the load, or whether the loads are just being fed from the battery bank. It also shows the power offset between the batteries and the PV inverter.

This is also where the symmetry of the panels, the type of batteries used for storage, the time of the day, whether the monitoring will be done on or off grid, the properties of the alternative AC sources, etc can be specified. It also has a push-button switch from which the island inverters can be turned on or off.

- Sensors: These include Insolation Sensor, Battery temperature sensor, Ambient Temperature Sensor, Motion sensor, etc.

- LAN: This is the communication network with which the grid communicates. The plant end and consumer end each have their components connected via CAT 5E twisted pair LAN cables. The plant and consumer ends communicate wirelessly via routers and repeaters. There is also room for remote monitoring in case internet access is available.

Based on this information, the various capacities of the proposed renewable power plants are shown in Table 5 below:

Table 5: Proposed Hybrid Plant Specifications

| PROPOSED PLANT | ESTIMATEDCAPACITY |
|---|---|
| Solar PV ($P_{PV}$) | 1000 kW (2x500) |
| Micro-Hydro ($P_{HYDRO}$) | 100 kW |
| Diesel Generator ($P_{Diesel}$) | 5 MW |
| Battery Bank $P_{Battery}$ | 17.83 MWh |

## VI. METHODOLOGY

As earlier mentioned, the aim for this research border on

*A. Determining how much the university spends per kWh at each point in time for the following reasons:*

- To adopt a tariff plan assuming each of the buildings supplied would have to pay for their energy usage
- To help the users cut down on their energyusage during peak periods and maximize usage when cost of generation is much lower.

*B. Determining a minimized operational cost for the proposed system using the Revised Simplex method*

The development of this pricing template will look at two (2) cases as derived from the load schedule from both plant and consumer-side:

- Case 1: Running purely on diesel generators for 24 hours for the smooth running of university activities
- Case 2: Installing a 1MW solar plant and a 100 kW micro-hydro plant and running solely on it.

✓ Case 1
From the information on Tables 3, 4 and 5, assuming the diesel generators supply the only power to the university, the cost of supplying the installed load purely on diesel will be **N41.07/kWh**

✓ Case 2:
When two 500kW solar farms and a 100kW microhydro plant are used, The cost per kWh will be **N3.30/kWh**

## VII. OPTIMIZATION OF OPERATIONAL COST

From the cost functions derived from the two cases above, the operational cost was summarized into a linear optimization problem where it was necessary to determine the minimum operational cost for the proposed plants tofurnish a load of 4MW for at least 22 hours daily.

From our scenario, we have a combined renewable plant (PV+ battery + Micro-Hydro) of capacity 1.1MW which is expected to supply for at least 12 hours daily with a per kWh cost of N3.30 with availability factor of 0.4 based on the average sun-hours of the location of our case study. Also a combined diesel capacity of 5MW is scheduled to supply for at least 6 hours daily when the renewable plant is not available with a per kWh operational cost of N41 and availability factor of 0.7.

Hence our optimization problem becomes Minimize $C = 3.3x + 41y$

Subject to the constraints $1.1x + 5y \geq 4$

$12x + 6y \geq 22$

$0.4x + 0.75y \geq 1$

$x \geq 0;\ y \geq 0$

where x = renewable plant function;y=diesel function

Using the dual problem solution to revert the minimization problem into a maximization problem, our initial tableau becomes

Table 6: Initial feasible solution of Cost minimization

| Basic variable | P | s | t | u | x | y | RHS |
|---|---|---|---|---|---|---|---|
| P | **1** | **-4** | **-22** | **-1** | **0** | **0** | **0** |
| a | 0 | 1.1 | 12 | 0.4 | 1 | 0 | 3.3 |
| b | 0 | 5 | 6 | 0.75 | 0 | 1 | 41 |

P is our new objective function in the dual solution;
s, t, u are our new non-basic variables and a and b are ourslack variables.

Table 7: Revised Simplex tableau after first iteration

| Basic variable | P | s | t | u | x | y | RHS |
|---|---|---|---|---|---|---|---|
| P | 1 | -1.98 | 0 | -0.274 | 1.826 | 0 | 6.05 |
| x | 0 | 0.092 | 1 | 0.033 | 0.083 | 0 | 0.275 |
| y | 0 | 4.45 | 0 | 0.55 | -0.5 | 1 | 39.35 |

Table 8: Revised Simplex tableau after the 2nd iteration,

| Basic variable | P | s | t | u | x | y | RHS |
|---|---|---|---|---|---|---|---|
| P | 1 | 0 | 21.48 | 0.44 | 11.626 | 0 | 11.96 |
| x | 0 | 1 | 10.87 | 0.04 | 0.902 | 0 | 2.99 |
| y | 0 | 0 | -48.37 | 0.39 | -4.51 | 1 | 26.04 |

The dual method gives the same value for C and P. Hence our optimal cost of operation C will be N11.96/kWh when the cost of renewable and diesel components are N2.99 and N26.04 respectively.

## VIII. RETURN ON INVESTMENT

The return on investment can be calculated by accumulating the daily monetary savings per kW over a period of time. Using the optimized operational cost, Total daily savings is

N11.96/kWh/day x 4000kW x 24h = N1,148,160/day

The total investment on 2 x 500kW solar farm and a 100kWmicrohydro is N935,267,000

Dividing the daily savings per kW the investments will givethe number of days after which we will break even. i.e N935267000/ (N1148160/day) = 814 days 14 hours

≈ 2 years, 2 months, 22 days and 14 hours after commissioning

## IX. CONCLUSION & RECOMMENDATION

Based on the above data and cases studied,

- It is possible to know the optimal running costs and savings
- The possible return on investment while implementing either of the renewable energy options was a little over 2 years
- A benchmark for tariff structure development based on the optimal operational cost for scenarios where individual buildings may take financial responsibility for their energy consumption such as to optimize profit.
- The use of more accurate optimization methods should be is recommended while considering more practicable factors and for better results.

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