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Optimal Load Shedding Based On Hybrid Energy Generation

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ORIGINAL RESEARCH

Abstract— The demand for electricity is growing at an exponential rate with no corresponding increase in the electricity production, which has led to voltage collapse in many practical power systems all over the world. This has, therefore, been a serious concern to power system engineers, investors and utilities as its effect is highly detrimental to power system operation and its reliability. Consequently, in the quest for providing solutions to this problem, integration of various renewable energy sources are deployed in recent years. This paper, therefore, presents an effective approach to solving voltage collapse problems through load shedding optimization. HOMER software was deployed due to its great features of quality design and evaluation, coupled with its technicality and economical options for both standalone and grid-connected power system. The results show that the utilization of the hybrid Hydro/PV produces 91kWh annually, whereas 88.5% of the electricity is produced by hydroelectric system while the remaining 11.5% of the electricity comes from the integrated photovoltaic system with excess electricity of 84kwh per year. The results obtained, therefore, show that there is an assurance of stable electricity with the introduction of backup battery banks even with the intermittent nature of the renewable energy systems.

Keywords— Hybrid renewable system, Homer software, Load shedding, Optimization, Voltage stability

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1 INTRODUCTION

In the olden days, insignificant number of blackouts and voltage collapses were experienced by the power networks. This is due to the fact that the generated power required to meet the system load demands plus losses are usually in abundant. In recent times, several voltage collapses within modern power networks have been recorded due to insufficient generated power. To solve these problems, one of the efficient ways has been through load-shedding.

The primary purpose of using load shedding is to reduce fluctuation and unsteadiness of the voltage. This reduces, to the barest minimum, the voltage collapse experienced by the power networks.

As a matter of fact, the use of fossil fuel for power generation is no longer sustainable & economical, which brings about the adoption of pollution-free renewable energy sources. Renewable energy are natural resources which are abundantly found anywhere. Although these renewable energy sources have a lot of benefits associated with them, they are not without limitations.

Hybrid Renewable Energy System (HRES) involves the use of different sources of energy to supplement and contribute additional electric energy to the grid. Despite the fact that, the startup cost is huge, the associated lowest Net Present Cost (NPC) and Operation and Maintenance costs (O&M) make it increasingly plausible. The cost of supply of sustainable power source may not be a financially savvy alternative for remote applications except if suitably supported or subsidized by the government.

In this paper, a load shedding optimization-based approach is employed to limit the voltage collapse within structurally weak power systems.

2 LITERATURE REVIEW

In the quest for providing efficient solutions to voltage collapse issues in modern power systems, various methodologies have been deployed and documented in the open literature. For instance, in (Luan *et al*), focused on seeking for ways to restore supply and also to carried out desirable load shedding within a distribution networks with help of genetic algorithm. In (Glasnovic & Margeta, 2009), addressed the greatest operational performance of the Photovoltaic plant considering were sizing model formulation of energy demand. In (Kusakana *et al, 2009),* studied the likelihood of producing low-cost electricity using the fusion of stand-alone solar and micro hydro-power.

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Section B- ELECTRICAL/COMPUTER ENGINEERING & RELATED SCIENCES

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In (Jurasz & Ciapala, 2017), formulated a mathematical model based on mixed integer programming to know the configuration parameters for a hydro/PV system through simulations. In (Beluco *et al, 2015),* discovered that in order to reduce electricity instability at the consumer ends the utilization of both hydro/PV plant should be adopted.

In (François *et al, 2016*), showed that to reduce electricity fluctuation in northern Italy, the combination of photovoltaic power and run-of-the-river type of hydropower could be used. In (Kougais *et al, 2015*), discovered that adjusting the positioning of the solar system could improve the totality that takes place between hydropower plants and photovoltaic system.

Although the existing studies have contributed in a significant measure in this research area, the major bottleneck is that their studies do not provide backup system knowing fully well that hydro/PV is climate-dependent.

This paper, therefore, explores the use of the benefits associated with the hybrid hydro/PV system in meeting the electricity demand. This could be further improved through optimization of the multiple system configuration.

3 METHODOLOGY

There are various forms of optimization algorithms and artificial intelligence methodologies that have been applied, to tackle this problem. Such approaches include fuzzy logic, differential evolution, particle swarm optimization and so on. In this paper, a hybrid-based optimization method is presented to significantly reduce the load shedding as well as the frequent voltage collapse within power systems.

In this study, Hybrid Optimization Model for Electrical Renewable (HOMER) is used. It is a micro power optimization software which is utilized for modeling the hybrid hydro/PV system for the load consumption of a community under study. This method is used as energy wheeling by taking advantage of the existing transmission line as bridge that connects the power provider and the power consumer together. It also creates a means of backup electricity due to the intermittent nature of the renewable energy sources.

3.1 MATHEMATICAL FORMULATION OF THE PROPOSED LOAD SHEDDING SCHEME

The adoption of linearized model is applied for the formulation of the intended load shedding plans. In (Charoenphan *et al*), load requirement is divided at each bus depending on the installed transformers. Although, the financial implication for this proposed load shedding approach has a massive initial cost. It is associated with lowest Operation and Maintenance cost (O&M) with span of longer lifecycle.

The objective function for the problem is modeled as;

$$Min(\sum_{i=1}^{N} C_i P_{Li} X_i) \qquad (1)$$

Subject to

$$V_{k\min} \leq V_{ko} + \sum_{i=1}^{N} [[Jc_{ki}] + \propto_i [Jd_{ki}]][P_{Li} X_i] \leq V_{k\max} \qquad (2)$$

$$Q_{g\min} \leq V_{ko} + \sum_{i=1}^{N} [[Gc_{gi}] + \propto_i [Gd_{gi}]][P_{Li} X_i] \leq Q_{g\max} \qquad (3)$$

$$I_{lo} + \sum_{i=1}^{N} [[JIa_{li}] + \propto_i [JIb_{li}]][P_{Li} X_i] \leq I_{l\max} \qquad (4)$$

$$\lambda_{lo} + \sum_{i=1}^{N} [J\lambda_{li}][P_{Li} X_i] \leq \lambda_{l\max} \qquad (5)$$

$$X_i \in \{0,1\} \qquad (6)$$

where X_i indicates the ON/OFF position of the transformer i using a binary number. P_{Li} is the number of base load at the loading transformer i. N is the number of transformers. g is number of generators. k is number of buses or substations; and l is number of transmission lines.

As presented in equation (2) to (4), four main constraints are considered in this paper. The first aspect is the voltage level limit shown in equation (2), the second aspect is the reactive power generation limit shown in equation (3), the third aspect is the extent current shown in equation (4) and the last constraint is the stability voltage described through the PQVSI index.

Due to voltage level limit linearization, the connections between the bus voltage and complex power under ZIP load model as follows:

$$P_i = \sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \qquad (7)$$

$$Q_i = -\sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) \qquad (8)$$

$$P_i^L = P_{0i}^L \lfloor a_i |V_i|^2 + c_i \rfloor \qquad (9)$$

$$Q_i^L = Q_{0i}^L \lfloor d_i |V_i|^2 + f_i \rfloor \qquad (10)$$

Where P*i* & Q*i* are the demand active and reactive power at bus *i*. V*i* & V*j* is the magnitude of voltage at bus *i* & *j*. Y*ij* is the magnitude of (i, j) element of Y_{bus} admittance matrix. θ_{ij} is the angle of (i, j) element of Y_{bus} admittance matrix, δ_i & δ_j is the angle of voltage at bus *i* & *j*.

The equation (7) – (10) described the linearized forms of the load model and to determine reactive power generation limit using linearization.

$$\begin{bmatrix}\Delta P_G\\ \Delta Q_G\end{bmatrix}=\begin{bmatrix}G_a & G_b\\ G_c & G_d\end{bmatrix}\begin{bmatrix}\Delta P_o\\ \Delta Q_o\end{bmatrix} \tag{11}$$

where,

$$\begin{bmatrix}G_a & G_b\\ Gc & G_d\end{bmatrix}=\left(\begin{bmatrix}\frac{dP}{d\delta} & \frac{dP}{d|V|}\\ \frac{dQ}{d\delta} & \frac{dQ}{d|V|}\end{bmatrix}+\begin{bmatrix}\frac{dP^L}{d\delta} & \frac{dP^L}{d|V|}\\ \frac{dQ^L}{d\delta} & \frac{dQ^L}{d|V|}\end{bmatrix}\right)\begin{bmatrix}Ja & Jb\\ Jc & Jd\end{bmatrix}+\begin{bmatrix}\frac{dP^L}{dP_0} & \frac{dP^L}{dQ_o}\\ \frac{dQ^L}{dP_o} & \frac{dQ^L}{dQ_o}\end{bmatrix} \tag{12}$$

$$\begin{bmatrix}Ja & Jb\\ Jc & Jd\end{bmatrix}=-\left(\begin{bmatrix}\frac{dP}{d\delta} & \frac{dP}{d|V|}\\ \frac{dQ}{d\delta} & \frac{dQ}{d|V|}\end{bmatrix}+\begin{bmatrix}\frac{dP^L}{d\delta} & \frac{dP^L}{d|V|}\\ \frac{dQ^L}{d\delta} & \frac{dQ^L}{d|V|}\end{bmatrix}\right)^{-1}\begin{bmatrix}\frac{dP^L}{dP_0} & \frac{dP^L}{dQ_0}\\ \frac{dQ^L}{dP_0} & \frac{dQ^L}{dQ_0}\end{bmatrix} \tag{13}$$

It is presumed that the load shedding will be executed in a manner that both the real and reactive power loads would be cut-off at defined ratio. Hence, equation (11) may be manipulated to (14).

$$[\Delta Q_G]=[[Gc]+\propto[Gd]][\Delta P_o] \tag{14}$$

The transmission line complex power flow is dependent on the PQVSI index. Consequently, the index linearized form can be written as:

$$[\Delta\lambda]=\left[\frac{\partial\lambda}{\partial P_{ij}}\right][\Delta P_{ij}]+\left[\frac{\partial\lambda}{\partial\theta_{ij}}\right][\Delta\theta_{ij}]+\left[\frac{\partial\lambda}{\partial|V_i|}\right][\Delta V_i] \tag{15}$$

$$P_{ij}=|V_i||V_j||Y_{ij}|\cos(\theta_{ij}+\delta_j-\delta_i)-|V_i|^2|Y_{ij}|\cos(\theta_{ij}) \tag{16}$$

$$Q_{ij}=-|V_i||V_j||Y_{ij}|\sin(\theta_{ij}+\delta_j-\delta_i)+|V_i|^2|Y_{ij}|\sin(\theta_{ij})-|V_i|^2|Y_{sh}| \tag{17}$$

$$\tan(\theta_{ij})={}^{Q_{ij}}\!/\!_{P_{ij}} \tag{18}$$

$$[\Delta P_{ij}]=\begin{bmatrix}\frac{\partial P_{ij}}{\partial\delta} & \frac{\partial P_{ij}}{\partial|V|}\end{bmatrix}\begin{bmatrix}\Delta\delta\\ \Delta|V|\end{bmatrix} \tag{19}$$

$$\sec^2(\theta_{ij})[\Delta\theta_{ij}]=\begin{bmatrix}\frac{\partial\left({}^{Q_{ij}}\!/\!_{P_{ij}}\right)}{\partial\delta} & \frac{\partial\left({}^{Q_{ij}}\!/\!_{P_{ij}}\right)}{\partial|V|}\end{bmatrix}\begin{bmatrix}\Delta\delta\\ \Delta|V|\end{bmatrix} \tag{20}$$

For the load shedding to be done, both the real and reactive power would be eliminated at a defined ratio. Hence (19) to (20) becomes (21) to (22).

$$[\Delta P_{ij}]=[[JPa]+\propto[JPb]][\Delta P_0] \tag{21}$$

$$[\Delta\theta_{ij}]=[[J\theta a]+\propto[J\theta b]][\Delta P_0] \tag{22}$$

where,

$$[JP]=[JPa\quad JPb]=\begin{bmatrix}\frac{\partial P_{ij}}{\partial\delta} & \frac{\partial P_{ij}}{\partial|V|}\end{bmatrix}\begin{bmatrix}Ja & Jb\\ Jc & Jd\end{bmatrix}$$

$$[J\theta]=[J\theta a\quad J\theta b]=\frac{1}{\sec^2(\theta_{ij})}\begin{bmatrix}\frac{\partial\left(\frac{Q_{ij}}{P_{ij}}\right)}{\partial\delta} & \frac{\partial\left(\frac{Q_{ij}}{P_{ij}}\right)}{\partial|V|}\end{bmatrix}\begin{bmatrix}Ja & Jb\\ Jc & Jd\end{bmatrix}$$

Substitution of equations (14), (21) and (22) into equation (14) results in a, linearized form of PQVSI as follows:

$$[\Delta\lambda]=[J\lambda][\Delta P_0] \tag{23}$$

where,

4 RESULTS AND DISCUSSION

The name of the community used as a case study in this paper is Olorunsogo, which is located at Abeokuta, Ogun State. Although in this community, there are various type of residential buildings, this paper centers on a three bedroom residential building. The total number of houses considered is fifty (50) with a consideration on basic electrical appliances such lightning, television, sound system, cable TV etc.

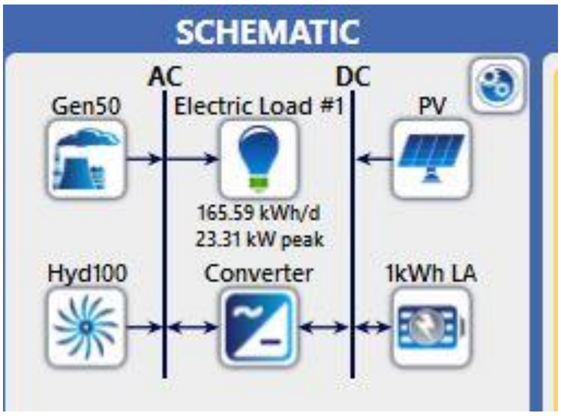
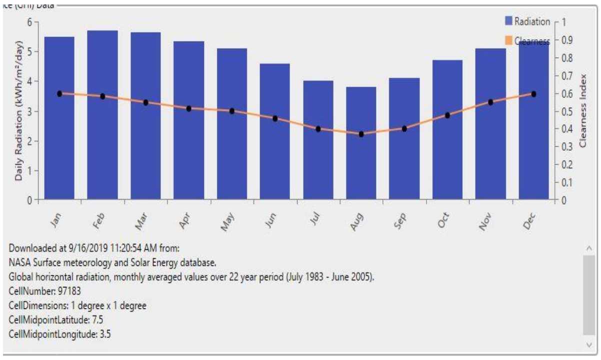


Fig. 4.1. Schematic Design

The above Fig. 4.1 shows the schematic design of the system with the photovoltaic power generation. The annual average of solar irradiation is estimated 4.91 kWh/m²/day as shown on Fig. 4.2 below.



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NASA Surface meteorology and Solar Energy database.
Global horizontal radiation, monthly averaged values over 22 year period (July 1983 - June 2005).
CellNumber: 97183
CellDimensions: 1 degree x 1 degree
CellMidpointLatitude: 7.5
CellMidpointLongitude: 3.5

Fig. 4.2. Monthly Average Solar Global Horizontal Irradiance chart

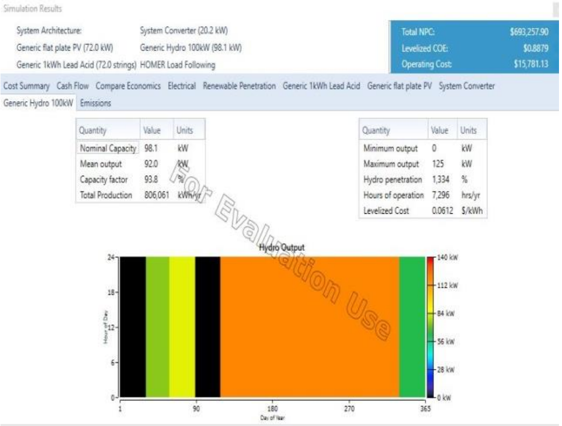
Production	kWh/yr	%
Generic flat plate PV	104,326	11.5
Hydro	806,061	88.5
Total	910,387	100

Consumption	kWh/yr	%
AC Primary Load	60,398	100
DC Primary Load	0	0
Deferrable Load	0	0
Total	60,398	100

Quantity	kWh/yr	%
Excess Electricity	848,378	93.2
Unmet Electric Load	43.9	0.0726
Capacity Shortage	60.4	0.0999

Quantity	Value	Units
Renewable Fraction	100	%
Max. Renew. Penetration	78,661	%

Fig. 4.3. Monthly Electric Production



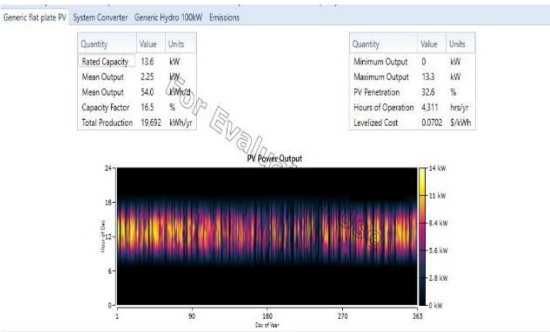
System Architecture: System Converter (20.2 kW)
Generic flat plate PV (72.0 kW) Generic Hydro 100kW (98.1 kW)
Generic 1kWh Lead Acid (72.0 strings) HOMER Load Following

Total NPC: $693,257.90
Levelized COE: $0.8879
Operating Cost: $15,781.13

Quantity	Value	Units
Nominal Capacity	98.1	kW
Mean output	92.0	kW
Capacity factor	93.8	%
Total Production	806,061	kWh/yr

Quantity	Value	Units
Minimum output	0	kW
Maximum output	125	kW
Hydro penetration	1,334	%
Hours of operation	7,296	hrs/yr
Levelized Cost	0.0612	$/kWh

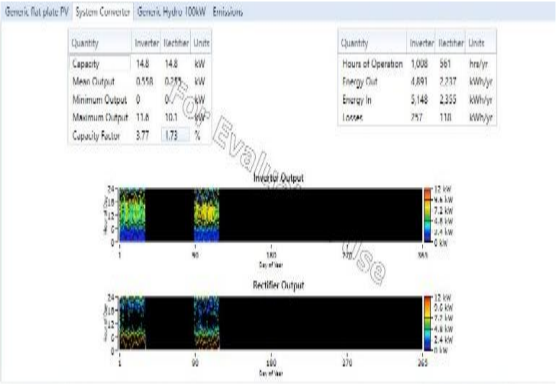
Fig. 4.4. Hydroelectric Output



Quantity	Value	Units
Rated Capacity	13.6	kW
Mean Output	2.25	kW
Mean Output	54.0	kWh/d
Capacity Factor	16.5	%
Total Production	19,692	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	13.3	kW
PV Penetration	32.6	%
Hours of Operation	4,311	hrs/yr
Levelized Cost	0.0702	$/kWh

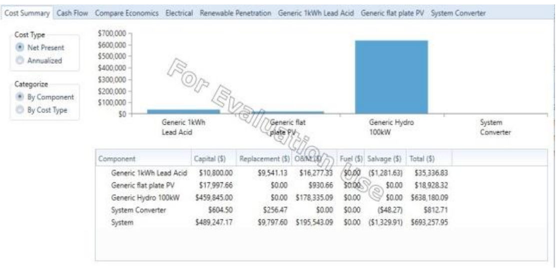
Fig. 4.5. PV Power Output



Quantity	Inverter	Rectifier	Units
Capacity	14.8	14.8	kW
Mean Output	0.558	0.255	kW
Minimum Output	0	0	kW
Maximum Output	11.6	10.1	kW
Capacity Factor	3.77	1.73	%

Quantity	Inverter	Rectifier	Units
Hours of Operation	1,008	561	hrs/yr
Energy Out	4,891	2,237	kWh/yr
Energy In	5,148	2,355	kWh/yr
Losses	257	118	kWh/yr

Fig. 4.6 System Converter



Cost Type
● Net Present
○ Annualized

Categorize
● By Component
○ By Cost Type

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Generic 1kWh Lead Acid	$10,800.00	$9,541.13	$16,277.33	$0.00	($1,281.63)	$35,336.83
Generic flat plate PV	$17,997.66	$0.00	$930.66	$0.00	$0.00	$18,928.32
Generic Hydro 100kW	$459,845.00	$0.00	$178,335.09	$0.00	$0.00	$638,180.09
System Converter	$604.50	$256.47	$0.00	$0.00	($48.27)	$812.71
System	$489,247.17	$9,797.60	$195,543.09	$0.00	($1,329.91)	$693,257.95

Fig. 4.7 Cost Summary

From the simulation, the PV panels rated capacity is 13.6KW at a 32.6% penetration and it is expected to be operation for 4,311 hours/year as shown Fig. 4.5. The modules initial cost is

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$17,997.66 and the operation cost is $930.66 with zero replacement cost as shown in Fig 4.7.

As extracted from the simulation, the nominal capacity of the hydroelectric is 98kW with mean output of 92kW at 1,334% penetration of the hydroelectric and expected to operate for 7,296 hours/year as shown in Fig. 4.4. The startup capital cost is $459,894 with operation and maintenance cost of $178,335.09 and has zero replacement cost as shown in fig 4.7.

From the simulation, the converters initial capital cost is $604.50 and replacement cost of $256.47 with zero operation and maintenance cost as shown in fig. 4.7. The inverter and rectifier is expected to operate for 1,008 and 561 hours/year respectively with losses of 257 and 118 kWh/year respectively as shown in Fig. 4.6.

Given from the simulation in Fig. 4.7, the renewable system has a total initial cost of $489,247.17 and operation and maintenance cost of $195,543.09 with replacement cost of $9,797.90 for a period of 25 years. The integration of hydro-PV would provide a constant power supply to the community with a provision of generator and backup bank storage to avoid power failure during poor weather condition.

The total production in a year from the hydro-PV is 910,387 kWh as shown in Fig. 4.3. Out of this, the hydroelectric system constitutes 88.5% renewables in the integrated system while PV system constitutes the remaining 11.5%.

It is clearly shown that renewable sources can meet up the electrical demand of the community with excess electricity up to 848,375kWh/year. This excess electricity takes places when the battery is fully charged (93% and above) and discharges less than expected.

5 CONCLUSION AND RECOMMENDATION

In this paper a complementarily design of a hybrid power system for energy efficiency using the Hybrid Optimization Model for Electric Renewable (HOMER), has been presented. The vast majority of the power in the ideal arrangement is gotten from the hydroelectricity and it gives a cheap source of power to the locality.

Based on the results obtained from this study, it is shown that the use of hybrid renewable power generation system to complement one another would totally eliminate voltage collapse and mitigate load shedding at the long run.

It is recommended that the Grid-Hydro-PV energy-based system unwavering quality can additionally be improved, if genuine information is utilized rather than integrated information and different strategies can be utilized to boost the PV generation like utilization of mount tracking system economically.

Although this study presented an economically viable approach of making provision for more electricity to consumers, the cost of supply of sustainable power source may not be a financially attractive alternative for remote applications except if suitably supported by the government or investors.

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