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Effects of PV and Battery Storage Technologies on the Optimal Sizing of Renewable Energy Microgrid

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Abstract: This paper presents analyses of the model for the optimum design of standalone hybrid microgrid. The model is developed with the aim of optimizing system component sizing that can reliably satisfy isolated loads. The objective function is to minimize the annual cost of the plant while taking all constraints into consideration. Mixed integer linear programming technique is used to solve the optimization problem. By applying some approximations, the output power of the wind energy conversion system is expressed as a linear function of wind speed. Effects of different PV technologies and the rated power of each unit have been investigated. The results have shown the ability of the proposed model by reducing the cost of energy by 89.35%, 90.26%, 88.3530%, and 89.99% for AP120, ASE 300, KC120 and SAPC165 respectively. In the same way the carbon dioxide emission is reduced by 83%, 82.82%, 82.51% and 73.48 in the same order of the PV modules. Also, the optimal design is sensitive to the rated power of the WECS and SECS, while the benefit-to-cost ratio and payback period are sensitive to the storage technology.

Keywords: Renewable Energy, Wind, PV, Battery Storage and diesel generator.

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1. GENRAL INTRODUCTION

Isolated loads and rural communities rely on the use of diesel generators for their daily energy needs. Fortunately, some of these places are blessed with renewable energy resources such as wind and solar power [1], [2], [3]. It has been suggested that these renewable energy resources be used to support the existing diesel generator. Due to the nature of the output power of the renewable energy resources, there is a need to add storage unit. Therefore, in order to achieve continuous, economical and reliable energy supply to these loads, there is a need to use all the mentioned resources together. Also, it is necessary to supply isolated loads with constant frequency and continuous electricity. These requirements make the design of a standalone microgrid very complex. In order to achieve these it is paramount to design all the parts correctly; therefore, proper sizing methodology of the hybrid microgrid system is required [4]. The design of the proposed system is site-specific and depends on the amount of renewable energy generation, cost prices of diesel and load [4]..

Several efforts have been made in the optimum design of hybrid microgrid. Particle swarm optimizations have been proposed in [5]- [6] . In [5], the system designed considered uncertainty in load, wind and solar radiation by modifying the particle swarm optimization. Optimum design of hybrid system consisting of wind, diesel generator and battery storage system has been proposed in [6], the design determines the reliability of the system considering component failures.

Multi objective optimization has been proposed in [7] and [8]. In [7] the objective function maximized reliability and minimized system cost of PV-wind hybrid system using constrained mixed-integer multi objective particle swarm optimization (CMIMOPSO). In [8], the cost of electricity, customer outage and emission pollution of a microgrid have been optimized.

In [10 a non-dominated sorting genetic algorithm (NSGA II) was used for optimum design of hybrid microgrid considering the characteristics of lead acid; the model minimizes cost of generation and battery life loss. Zhang [9] proposed Dividing Rectangle (DIRECT) algorithm for the design of PV/wind/diesel/storage system. Simulated annealing has been utilized in [10] for optimum operation and the unit cost of the system. Other factors that affect the optimum operation such as uncertainty in the load were not given due attention. Method for determining the wind-PV generation capacities based on numerical algorithm has been developed in [11]. Time matching simulation has been proposed in [12] considering battery management; however the system may not be reliable due to the absence of diesel generator. Generally are three main approaches in the optimal configuration of hybrid system technically and economically. This includes iterative, the probabilistic and trade-off approaches [13].

Also, other factors such as PV technology, temperature, customer damage functions that may affect the optimum configurations have not been given the expected attention. For realistic planning, there is the need to analyse the effects of these factors on the optimal design of microgrid. Hence the need for the development of another methodology that could be used in order to analysed effects of some of them in the optimal design of a standalone microgrid. This paper presents the optimal design of standalone microgrid considering the penalty as a result of carbon emission into the atmosphere. In addition, the effects of different types of PV systems and the rated power of each unit on the optimal system configuration have been investigated. In distinct to other literatures, the effects of different PV technology on the the optimum design of microgrids is considered in this work using AP120, ASE300, KC120 and SAPC145 [14]-[15]. Also, the effect of storage technology on the cost of energy for optimum design which has not been given the necessary attention was investigated using lead acid battery, nickel-cadmium battery, Sodium-polysilfied batteries, electrochemical capacitor, SMES, Flywheel energy storage , Sodium-Sulpur batteries, Zinc-Bromine batteries, VRB and batteries.

This paper is divided into sections including system configurations and operations in section 2, mathematical models of the WECS and SECS as presented in sections 2.1 and 2.2, followed by the formulation of the problem including the objective function and the system constraints in sections 3 and 4, the economic modeling is presented in section 5, the application of the proposed method is shown in section 6, the effects of the units rated power on the optimal design is presented in section 7, section 8 is on the effects of storage technology on the optimum design, finally the conclusion is presented in section 9.

2. SYSTEM CONFIGURATION AND OPERATIONS

In this section, a schematic diagram of the proposed hybrid system is presented in Figure 1. It can be seen that the proposed system has five major building blocks. These include Wind Energy Conversion System (WECS), Solar Energy Conversion System (SECS), Storage system, Diesel Generator (DG) and Static Energy Conversion System (STECS). These components operate in parallel to guarantee continuous power supply to the load. The storage system is connected to reduce the fluctuations and store the excess power produced by the renewable energy sources. When the power produced by the two renewable energy sources is less than the demand, the battery supply the deficit. On the other hand, when the power supplies by both renewable energy sources and the battery is less than the demand, the diesel generator operates to supply the deficit.

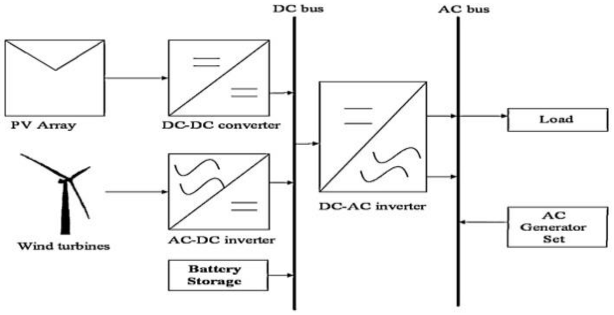

Figure 1: Proposed hybrid Microgrid

2.1 Output Power of Wind Energy Conversion System

The power output of wind energy conversion system is a function of the wind speed, these results in different design alternatives [16]- [17]. Therefore, the power output of wind energy conversion system is expressed as a function of rated capacity and a variable that is a function of the wind speed. Modelling using this approach, the number of the wind turbine generator is modelled as a decision variable, such that, the model decides on the capacity for each design. This presentation enables to linearly approximate the wind speed and output power in the range cut-In velocity and the rated velocity of the wind turbine generator (Vci<V<Vr) [18] . After the random distribution is obtained, the power output of the WECS is expressed as a function of wind speed and determined using Equation (1) [18],

$$P(v) = \propto P_r \tag{1}$$

$$\propto \; = \begin{cases} \frac{V_i - V_{ci}}{V_r - V_{ci}} & V_{ci} < V < V_r \\ 1.0 & V_r \leq V < V_{co} \\ 0 & V \leq V_{ci} \; or \; V \geq V_{co} \end{cases} \tag{2}$$

$\propto_{i,k}$ is a constant, and it can be observed that the output power can be determined as a piecewise linear relationship of the rated capacity (P_r). Therefore, the rated capacity of the WECS can be used as a decision variable. Hence, the model decides on the number of wind turbines for each design.

2.2 Output Power of Solar Energy Conversion System

This section presents the model used for the determination of the output power of the SECS. In [19]- [10], many models are proposed depending on the application. The proposed model utilized factors such as temperature, number of series and parallel connected cells and also, exploits how it operates under standard test condition, light intensity, and the ambient temperature. This presentation enables to study the effects of other factor that were not analysed in the literature [14]. The model used in the analysis is expressed according to the following expressions. Initially, the short circuit current of the PV module is defined [15].

$$I_{sc}(t) = I_{sco}\left(\frac{E_e(t)}{E_o}\right)[1 + \alpha I_{sc}(T_c(t) - T_o)] \tag{3}$$

Other models used in the determination of the PV output power include, maximum point current, open circuit voltage and maximum point voltage defined in Equations (4) to (6).

$$V_{oc}(t) = V_{oc} + N_s \delta T_c(t) \ln(E_e(t)) + \beta_{Voco} E_e(t)(T_c(t) - T_o) \tag{4}$$

$$I_{mp}(t) = I_{mpo}(C_o E_e(t) + C_1 E_e(t)^2)(1 + \alpha I_{mp})(T_c(t) - T_o) \tag{5}$$

$$V_{mp}(t) = V_{mp} + C_2 N_s \delta T_c(t) \ln(E_e(t)) + C_3 N_s \delta T_c(t) \ln E_e(t)^2 + \beta_{Vmpo} E_e(t)(T_c(t) - T_o) \tag{6}$$

Since the PV panels cannot use all the wavelengths of light in the solar spectrum, effective isolation is utilized in the design and therefore defined in equation (7),

$$E_e(t) = \frac{I_{sc}(t)}{I_{sco}(1 + \alpha I_{sc}(T_c(t) - T_o))} \tag{7}$$

In addition, the thermal voltage per cell ($\delta T_c(t)$) is defined in Equation (8).

$$\delta T_c(t) = \frac{nk(T_c(t) + 275.15)}{q} \tag{8}$$

Also, the temperature inside each cell ($T_c(t)$) is also defined as

$$T_c(t) = T_a(t) + \frac{NCOT - 20}{800} E(t) \tag{9}$$

Equations (3) to (9) combined together formulated the expression of the output power of the SECS as

$$PSEC\ (t) = I_{mp}(t) * V_{mp}(t) * N_{PV} \tag{10}$$

where, $PSEC$: PV output power: solar radiation of the operating point, output power under standard test condition, $T_c(t)$: PVcell temperature, $T_a(t)$: Ambient temperature, T_o: reference temperature of the model, $NCOT$: nominal cell operating temperature, k: Boltzmann's constant, n : empirically determined diode factor for each cell, αI_{sc}: normalized temperature for I_{sc}, β_{Vmpo}:temperature coefficient for V_{mp}, β_{Voco}: temperature coefficient for V_{oc} , $C_0 C_1$: empirically determined coefficient relating I_{mp}, $C_2 C_3$:empirically determined coefficient relating V_{mp},

Equation (10) enables to use the number of the PV panels as part of the design variable. The output of the SECS is made of a number of the PV panels connected in series ($N_{PV,}$) and parallel ($N_{PV,P}$). Therefore, the model determines the total number of connected PV panels. Depending on the application, the PV panels may be connected in parallel for higher current or in series for higher voltage.

3. OBJECTIVE FUNCTION

The objective function is developed to minimize the annual cost of the system. Therefore, objective function $F_{\min}(X)$ to be minimized is defined as follows,

$$F_{\min}(X) = ACC(x) + AOM(x) + ARC(x) + AFC(x) + AEC(x) \tag{11}$$

where, $ACC(x), AOM(x), ARC(x),\ AFC(x)\ and\ AEC(x)$ are the Annual Capital Cost, Annual Operating and Maintenance, Annual Recovery Cost Annual Fuel Cost and Annual Carbon emission costs respectively.

In this arrangement, the diesel generator operates only when the energy supply of the renewable resources and the battery cannot meet demand. Therefore, for every interval, the penalty; as a result of carbon emission is determined. The emission factor is assumed to be in the range of 30-50 \$/Ton [20]. The expression of the determination of the AEC is defined in Equation (12),

$$AEC(x) = \sum_{t=1}^{T} \frac{E_f * E_{cf} * P_{DG}(t)}{1000} \tag{12}$$

4. CONSTRAINTS

The constraints in this optimization maintain a balance between the power generation and system demand. In this case, the constraints are classified under three main sub headings [18]. These include power balance, energy balance and component rating constraints as defined in Equations (13) to (20).

$$PD_i + PWR_i + PSR_i + \eta_D \times q_{Di} - {}^{q_{ci}}/_{\eta_c} = P_{Li} \tag{13}$$

$$\sum_{i=1}^{T} q_{Di} \times \Delta t_i = \sum_{i=1}^{T} q_{ci} \times \Delta t_i \tag{14}$$

$$ES_i + q_{Di} \times \Delta t_i - ES_{i-1} - q_{ci} \times \Delta t_i = 0 \tag{15}$$

$$ES_i - \mathrm{QS} \leq 0 \tag{16}$$

$$ES_i - \gamma.\mathrm{QS} \geq 0 \tag{17}$$

$$PD_r - PD_i \geq 0 \tag{18}$$

$$PINV - PWR_i \times +PSR_i \times +\eta_D \times q_{Di} \geq 0 \tag{19}$$

$$PINV - PD_i + P_L \geq 0 \tag{20}$$

where, PD*r*, PWR, PSR, PINV and QS are the rated power per units for diesel generator, wind turbine generator, PV system, bidirectional inverter and battery storage respectively, q_{Di}, q_{ci}, η_c: charging ,discharging power and efficiency of the storage unit, ES: energy stored in the storage unit and P_L: load demand.

The decision variables according to the model for the whole system includes the number of WT, PV, DG, inverter-rectifier unit, storage, output power of diesel generator, previous and present storage level, charging and discharging powers at each hour, the rated power of wind and solar energy conversion systems. The model thereby, determined the optimal number of PV panels, wind turbine generators, diesel generators, storage and the inverter-rectifier units. In addition, the model also, decides on the output powers of the diesel generator and the storage levels at each interval. Due to the nature of the objective function, constraints and the expected output of the model, Mixed Integer Programming (MIP) is used to solve the optimization problem. Mixed integer optimization problem has the following standard form

$$\min_{x}(f^T x)$$

Subject to the constraints as follows:

$$\begin{cases} x(\text{intcon}) \\ A \cdot x \leq b \\ A_{eq} \cdot x = b_{eq} \\ lb \leq x \leq ub \end{cases}$$

where, $x(\text{intcon})$ is the integer constant, $f, x, b,\ b_{eq}$, lb, ub are vectors and A and A_{eq} are matrices.

5. ECONOMICS OF THE PROPOSED MODEL

The method used in estimating the annual cost of each component depends on several factors such as Capital Recovery Factor (CRF), Annual Replacement Cost (ARC) and Sinking Fund Factor (SFF). More details about these models are presented in this section.

5.1 Annual Capital Cost

The ACC needs to be economical for a payback period of n years and at interest rate (r). The ACC of each unit i is defined by

$$ACC_i = C_{cap} CRF(r,n) \sum_i^m C_i R_i \tag{21}$$

The CRF is defined as the ratio used to determine the present value (or a series equal to the annual cash flow) and expressed as

$$CRF(r,n) = \frac{i(1+i)^n}{(1+i)^n - 1} \tag{22}$$

where
C_i and R_i are the capital cost and rating of i^{th} unit respectively.

5.2 Annual Replacement Cost

The ARC is the cost of replacing a unit during the entire lifetime of the project. In this design, the unit that needs to be replaced is the battery. Other units do not need to be replaced, because their lifespan is the same as the project lifetime. Mathematically the ARC is defined as

$$ARC = C_{rep}.SFF\ (i,n) \tag{23}$$

C_{rep} is the replacement cost of the unit and SFF is defined as the ratio to calculate the future value of a series equal to the annual cost

$$SFF\ (i,n) = \frac{i}{(1+i)^n - 1} \tag{24}$$

5.3 Annual Fuel Cost

The fuel consumption of other units except DG is zero. Therefore, it is assumed that the system annual fuel consumption is equal to the annual fuel consumption of the DG. It can be defined as the accumulated fuel consumption from hourly fuel consumption of DG per annum. It is assumed to be a function of the CRF for the period of the project and is defined as

$$AFC = TFC \cdot CRF(r,n) \tag{25}$$

5.4 Annual Operating and Maintenance (AOM) Cost

There are several models for estimating the AOM system cost [18]. It is assumed to be a function of both inflation rate f and the lifetime (n years) of the project. Therefore, the AFC relates with the AOM as;

$$AFC = AOM \cdot (1+f)^n \tag{26}$$

6. APPLICATION OF THE MODEL

In order to test the application of the proposed design procedure, the assumed rated power of each unit are presented in Tables 1. In addition, more details on the PV module specifications are can be found in [15]- [21]. In addition, the cost data of each unit can be found in [9]-[10].

Table 1. Rated power of the base case

Source	Rated power
WT	100 Kw
PV	8 kW
DG	100 kW
Battery	185 kWh
Inverter-Rectifier	100 kW

The output of the optimization procedure is shown in Table 2. According to the AP120 module, the system contained 3x100 kW for WT, 12x8 kW for PV, 2x100 kW for diesel generator, 1x185 kWh for battery storage and 1x100kW for rectifier-inverter unit. In the same way, the optimal configuration for the ASE300 module is 3x100 kW, 1x8 kW, 1x100 kW and 1x185 kWh, 1x100kW of WECS, SECS, diesel generator, sbattery torage system and 1x100kW of rectifier-inverter unit respectively. KC120 module configuration include 3x100 kW, 2x8 kW, 1x100 kW, 1x185 kWh, and 1x100 kW of rectifier-inverter. Finally, SAPC145 has 3x100 kW of WECS, 1x8 kW SECS, 2x100 kW DG and 1x100 kW inverter-rectifier unit.

Critical examination of the results have shown that PV module technology affects the optimal design of standalone microgrid. In terms of energy contribution, WECS contributes more, followed by SECS and DG has the least contribution in all the PV modules analysed. The energy contribution of the SECS depends on the PV technology. In Figure 2, the energy contributions of SECS of each PV module is 29.4014%, 28.6885%, 28.3491% and 19.9344% for AP120, ASE300, KC120 and SAPC14 respectively. AP120 module is best for the environment due to the low power output of the DG unit.

Table 2. Output of the optimization

Source Type	AP120	ASE300	KC120	SAPC165
WT	3	3	3	3
PV	12	1	2	1
DG	1	1	1	2
Battery	1	1	1	0
Inverter-Rectifier	2	1	1	1

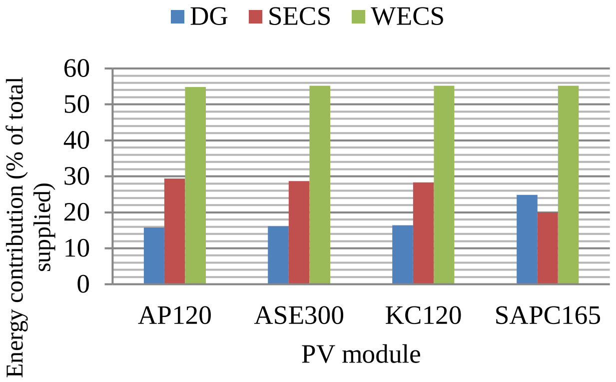

Figure 2. Energy contribution of each PV technology

Table 3. Cost of energy

Energy cost	AP120	ASE300	KC120	SAPC165
DG	0.1099	0.1099	0.1099	0.1099
Hybrid	0.0117	0.0107	0.0128	0.0110

The energy cost of each technology is shown in Table 3. It can be observed that ASE300 has the least energy cost, followed by SAPC145, AP120 and KC120 offers typo expansive. The result in Figure 4 shows that the annual carbon penalty cost is 3590$, 3639 $, 3995 $ and 3703$ for AP120, ASE300, KC120 and SAPC165 respectively. On the other hand, the penalty cost due to carbon emission as a result of the DG operation is 21,174$/yr. These have shown an 83.0%, 82.82%, 82.51% and 73.48 carbon savings for the AP120, ASE300, KC120 and SAPC165 respectively. It can be observed that the penalty cost is also sensitive to the PV module technology. Therefore, AP120 module is the most suitable for the environment.

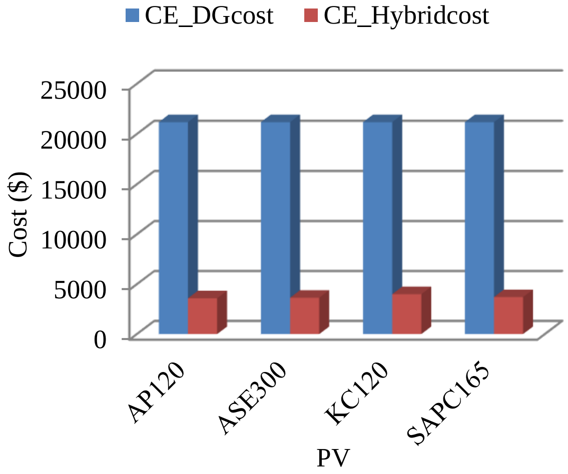

Figure 3. Annual carbon emission for each technology

7. EFFECTS OF THE RATED POWER OF EACH UNIT

The proposed method is suitable to study the effects of the rated power of each unit in the optimal design. In order to achieve this, the rated power of each unit is increased by 25%, 50% and 75%. The effects of this variation on the optimal design of the system have been studied in this section. The results are presented in Figures 4-7 for AP120 technology. Variations of the optimal design with rated power of WECS are shown in Figures 4. The effects of the rated power of SECS on the optimal design are also presented in Figure 5. Similarly, Figure 6 shows the optimal configuration considering rated power of DG. Optimal design considering increases in the rated power of the storage system is also shown in Figure 7. In general, the variation depends on the PV technologies. It has been observed that as the rated power increased, the number of energy units decreased. The result shows that in addition to the PV technology, the optimal design is sensitive to the rated power of the WECS and SECS. On the other hand, the optimal design is not sensitive to the rated power of the storage and the DG generator. The result shows the case of AP120 PV module only, other modules analysed are not shown here. Other PV module analysed are not shown here for the sake of brevity.

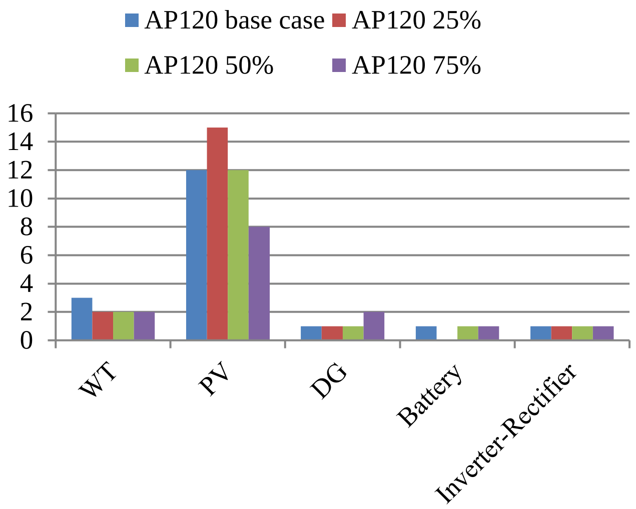

Figure 4. Variation of the rated power of WECS for the AP120 module

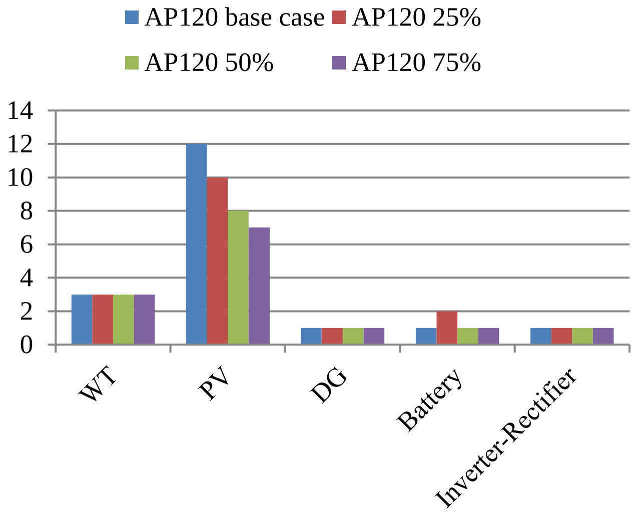

Figure 5. Variation of the rated power of SECS for the AP120 module

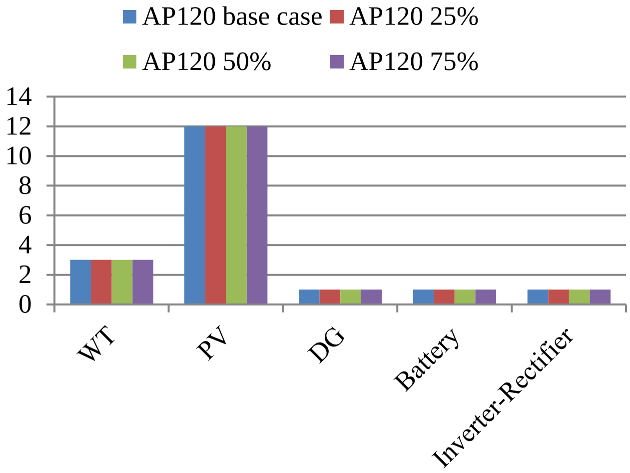

Figure 6. Variation of the rated power of DG for the AP120 module

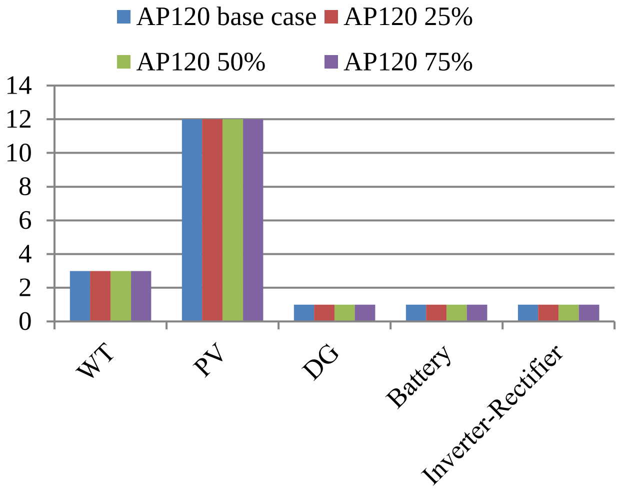

Figure 7. Variation of the rated power of storage for the AP120 module

8. EFFECTS OF STORAGE TECHNOLOGY ON THE OPTIMUM DESIGN

In this section, the effects of different energy technology on the optimum system configuration is considered. Some of the literature in the storage for the stand-alone microgrid were presented in [22] and [23]. In [22], the optimal ratings of different battery technology were analysed for minimizing the energy cost of wind-diesel microgrid. In [23], scheduling of a storage connected to isolated microgrid based on the knowledge expert system is proposed. Due to the result in the section 7, the analysis in this section was based on the AP120 PV module alone. Hence, more details about the storage technologies can be found in [22].

The data of each battery storage is shown in Table 4 and the results of different opimizations are presented in Table 5. The most sensitive component is the cost of energy ($/kWh), it actually changes with technology. It can be observed that lead acid, Sodium Polysulfide, ZBB and VRB batteries have lower cost of energy. This is followed by PSB, LI-ion, NI-Cad and Na-S in that order. Battery storages that have a lifespan greater than the project life are not considered. These include Electrochemical Capacitors, SMES and Flywheel energy storage systems. Also, their capital cost is very high compared to project cost, therefore it is assumed not suitable for the proposed application.

Table 4: Specifications of the battery

	Capial cost	Eergy rating (MW)	life (yrs)	energy eff.	charging eff.	Discharge eff.	Depth of discharge
Lead acid	50-150	0.001-40	5-15	70-80	95	80	70
Na-S	200-600	0.4-244.8	10-20	75-89	99	88	100
LI-ion	900-1300	0.001-50	14-16	75-95	99	95	80
VRB	600	2-120	10-20	65-85	98	85	75
PSB	300-1000	0.005-120	15	60-75	90	75	75
ZBB	500	0.1-4	8-10	65-85	98	85	75
NI-Cad	1197		10-15		85	65	70

Table 5: Impacts of battery technology on energy cost

Battery	Lead acid	Na-S	LI-ion	VRB	PSB	ZBB	NI-Cad
Energy Cost ($/kWh)	0.01228	0.01386	0.01336	0.01312	0.0133	0.0131	0.0134

In the same way, the energy contribution of each generating unit is presented in Figure 8 while the carbon emission effect is shown in Figure 9. It can be further affirmed that lead-acid battery is still the best for the standalone system. However, other battery storage technology might be suitable for higher application such as grid connected system due to high energy density and initial capital cost. The result further confirmed the dependence of the system performances on the storage technology. Therefore, it is critical for both the system operators and planners to know the suitable storage system economically and environmentally.

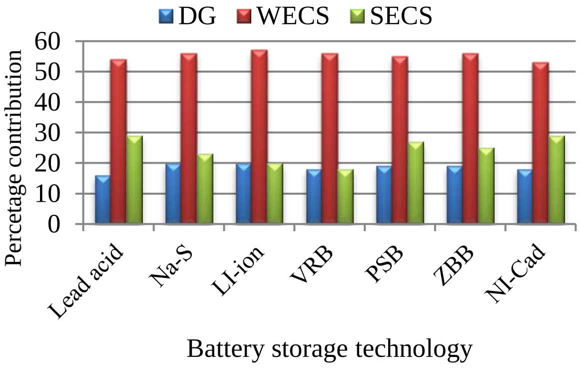

Figure 8. Energy contribution of different units

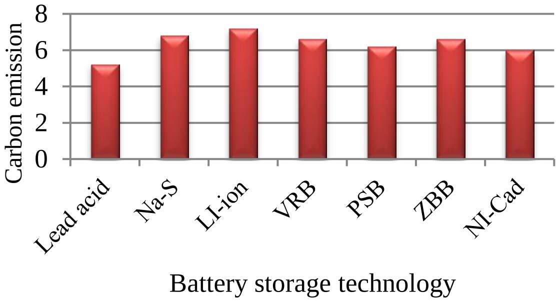

Figure 9. Variation of carbon emission with battery storage technology

9. ECONOMIC IMPACT OF THE PROPOSED MICROGRID

The main idea behind these assessments is to project the economic benefits and decide on whether the proposed microgrid is economically viable. This was achieved by the use of economic indicators such as Net Present Value (NPV), Benefit-Cost Ratio (BCR) and Payback Period (PBP).

9.1 Net Present Value (VPB):

This is defined as the net value of benefits (B) and cost of the project, discounted back at the beginning of the investment. The benefit in this case is the income from selling the generated power while; the cost is the total capital investment cost and the accumulated annual operation and maintenance cost (A). In some cases the cost can be assumed to be about 2% of the total project cost. In this design the actual data is used and the mathematical expression for the determination of the NPV is given by

$$NPV = NPV(B) - [IC + NPV(A)] \qquad (27)$$

where;-
$NPV(B)$: the Net Present Value of Benefits
IC: the Initial Cost (total capital investment) and
$NPV(A)$: the Net Present Value of the Annual cost, and

$$NPV(B) = B[(1+I)^n - 1]/I(1+I)^n \qquad (28)$$

$$NPV(A) = A[(1+I)^n - 1]/I(1+I)^n \qquad (29)$$

where;-
B: All benefits
A: Annual operation and maintenance cost
I: the real rate discount.

Using Equations (27) to (31), the net present value of the proposed microgrid in the study area is obtained and used in sections 8. 2 and 8.3. The result shows that NPV is > 0, hence, the project is economically possible. which means, it will bring more profit to the investor .

9.2 Benefit Cost Ratio (BCR)

This index is defined as the ratio of the net present value of the total benefits to the net present value of all the cost plus the investment cost. The BCR of the project is obtained by using

$$BCR = NPV(B)/[IC + NPV(A)] \qquad (30)$$

The result is presented in Figure 10 which shows that BCR is > 0. This further affirmed the NPV claim; therefore the project is also economically acceptable. It can be regarded as the profitability index as interpreted by most investors easily. The result also confirmed the effects of the battery storage on the optimum design of microgrids. Therefore, Lithium ion battery is the best in terms of the profitability index.

9.3 Payback Period (PBP)

The payback period is the year (n) in which the net present value of all benefits will be equal to the net present value of all the costs plus capital investment, therefore at PBP; the Equation (30) is then equated to zero, which gives;

$$NPV(B) = [IC + NPV(A)] \qquad (31)$$

Finally solving for n results in

$$n = -In(1 - \frac{(I\times IC)}{(B-A)})/In(1+I) \qquad (32)$$

According to the result obtained in Figure 11, it can observe that the project is economically possible because the payback period is less compared to the lifespan of the project. The result shows that, lead acid battery with less energy cost takes longer time to return the money invested and so, from the investor point of view may not be the best for the chosen environment. Using this index, the project will be better using sodium sulphide battery storage.

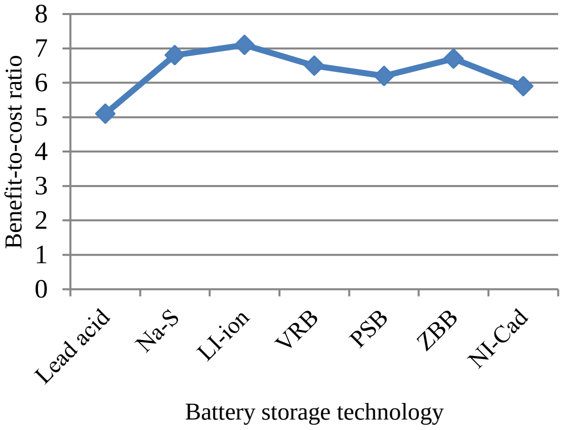

Figure 10. BCR of different battery

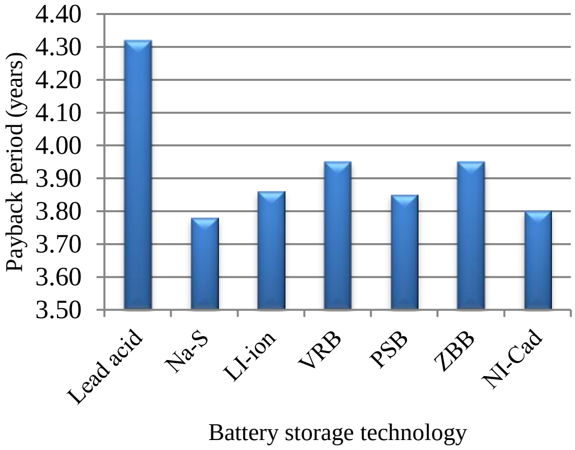

Figure 11. Payback period

10. CONCLUSION

Based on the presented results, this paper presented another method for the optimal design of standalone microgrid based on mixed integer programming. The results have shown that realistic optimal planning of the system with the effects of different PV modules within the grid need to be considered. Also, optimal design of the proposed system is sensitive to the rated power of the each unit and from the PV technologies, AP120 is the most suitable due to the higher output power. This reduced the projection for the use of the DG connected to the system and consequently reduce the cost implication on the system. However, ASE300 has the least energy cost due to the less number of series connected cells. Therefore; the energy cost is sensitive to both the storage and PV module technology. Abrasively, neglecting the penalty cost due to the carbon emissions leads to underestimation of the annual cost of the plant.

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