Optimal load dispatch strategies for a hybrid system using renewable energy sources

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Abstract. Recently, the idea of hybrid power systems (HES) has attracted interest for the electrification of isolated or energy efficient areas. This document examines the modelling and optimal dimensions of a hybrid microgrid using different dispatch strategies. The sizing of the HES components such as Photovoltaic panels, Batteries, Inverter, a Diesel generator has been optimized by three strategies: (i) load tracking, (ii) cycle load, and (iii) combined dispatch. The location of the case study is in a rural community in Ecuador whose load profile is 17 kW. By utilizing HOMER software, optimization for the HES was achieved with the Combined Dispatch strategy (CD) which presented the minimum levels in the net annual cost (NPC), initial capital, levelized cost of energy (LCOE) of $ 90,073.10, $ 21,208 and $ 0.2016 / kWh, respectively. The conclusions offer a guide to consider the resources and generation combination essential for the optimal operation of an island microgrid with different dispatch scenarios.

1. Introduction
There is an abundance of isolated places around the world in which power supply through the central electrical Grid is neither economical nor technically feasible due to their geographic conditions. These systems are normally referred as an autonomous Microgrid. [1] Most of these microgrids usually have poorly optimized systems in which they normally operate with a diesel generator which is not only a terrible option money-wise due to the volatility of oil prices but also negatively affecting the environment due to gas emissions produced when burning through the fuel. In these cases, Off-grid systems involving renewable energy can be a feasible solution. [2] Generation units in Microgrids can be Diesel or Thermal Generators, and Renewable Energy Sources (RES), can be Photovoltaic (PV) Panels, Wind powered Turbines (WT), Battery Energy Storage Systems (BESS) or Fuel Cells. These technologies offer feasible energy solutions in remote locations but due to their stochastic nature, their operation may or not be conditioned. [3] This depends on whether the system contains a reliable generation unit and batteries as backup units. Hence a hybrid system is preferable, requiring optimal sizing and dispatch strategy to offer a higher reliability, and quality energy than a system based on a fossil fuel energy source. [4]
Recent research has successfully implemented different hybrid energy systems. PV panels, Wind turbines, Diesel Generators are the most used resources in these investigations. Also, Battery banks, Fuel cells and Hydro pumps are the common denominators for energy storage.
A. Toopshekan [5] In his research he presents the dispatch of renewable and sustainable energy on a system composed of solar panels / WT / diesel / battery, the researchers come up with a novel control strategy through MATLAB and HOMER, the results show a 9% improvement in cost over two other dispatch strategies by load tracking and by cycle load. The simulations were carried out for different sensitivities and electrical loads in Iran.

N. Sifakis [6] Presents the optimization analysis of a RES with connection to the electrical grid in a seaport, in the research they compare the impact of three storage technologies, and two dispatch strategies in 17 scenarios with respect to possible combinations taking into account the energy cost, future employability in addition to carbon footprint, best results were obtained with vanadium redox flow batteries offering up to 10h autonomy, Supplied energy cost is at 12.9 c € / kWh In all the important presentations presented, the cost of energy is lower than the rate of the conventional network with one point reducing the environmental impact.

K. Liu [7] used particle swarms’ optimization to optimize the micro-grid operation of a system containing Gas turbines, Fuel Cells, wind power and PV power generation, In their control strategy, the first step is to choose whether PV or Wind power is the one with the least costs and less pollution next the fuel cell power when the supply is insufficient, and lastly the Gas turbine Power. Results show that the particle swarms’ optimization technique used is a fast solution which can greatly improve power quality, reduce costs operation and maintenance costs while also lowering environmental pollution. K. Kuzakana [8] used a simulation dispatch method based on MATLAB in a rural residential home and a transmitter-receiver station case study, he compares the obtained results to a setting in which the Diesel Generator is the sole energy supplier. The results show noteworthy energy savings utilizing the modelled optimal energy control strategies.

J. Lu [9] sought to substitute an old Diesel generator in a remote sea Island with a Photovoltaic-Eolic-Diesel-Batteries HES using HOMER as a method to optimize and simulate the system, using different combinations of hybrid energy sources and storage to establish the optimal model of the system, through simulations they concluded that the HES can get rid of the Diesel-based Generation dependency to operate in a more cost-efficient manner. X Liu [10] Optimized an AC/DC hybrid microgrid of independent operation by means of a modified artificial BCA, building an optimal model with an economic approach. The objective function was built around reducing environmental emissions, Finally the optimal sizing model demonstrates that it has a lower cost when compared to the traditional model. S. Oh [11] Proposed a predictive Dispatch strategy and did a real-time simulation to prove near optimal performance on the management algorithm. The case study was an islanded microgrid, their optimization considered energy costs, Generator and battery life cycles utilizing normal parameter values. The simulations show that the algorithm provides an optimal control for the system with a minimum impact from erroneous load demand prediction to the algorithm’s performance.

This paper analyses a case study on an isolated community located in Colta-Ecuador, which is currently using a sole Diesel generator as their means of energy supply and presents an optimized off-grid model using renewable energy sources in conjunction with a diesel generator.

People living in this area have very low income, so the main focus will be utilizing the dispatch strategy that allows the lowest energy cost throughout the project’s life. Three different dispatch strategies are considered for a comparative performance analysis. Section II Consists of the design and modelling of the micro-grid system in HOMER. Section III contains the simulation and optimization results. And finally, section IV Draws the conclusions.

2. Methodology
This review analyses the viability towards a new hybrid microgrid structure for a rural isolated community, considering solar energy resource as its main source of power, while also including several components such as a battery bank and a DC/AC converter.
The correct analysis of a certain renewable energy project requires the use of proper criteria in the selection of the system’s location to ensure the accurate operating behaviour before the different scenarios. For this purpose, the subsequent analysis frameworks are adopted. Please follow these instructions as carefully as possible so all articles within a conference have the same style to the title page. This paragraph follows a section title so it should not be indented.

2.1. Case Study's characteristics and load profile
The case study is placed in the “Castug Alto” community located in Colta – Ecuador. This community is composed of 40 households with an approximate population of 120 people. Electrical Energy generation is delegated to a single conventional Diesel Generator with a 10-kW throughput which is also near the end of its life cycle and with an Operation and Maintenance cost of around $ 1137.33 per year.

The cost of diesel fuel in Ecuador has seen a price increase from 1.48 USD per gallon to 1.52 USD per gallon. This increase also impacts the energy production costs [12]. Given the increased Diesel price, the cost of fuel consumption per year equates roughly to $ 4240.

The Diesel Generator has been replaced every time it ceases to function in its entirety, so the time between replacements varies greatly.

Residential households in this community have a very low load demand on their electronics and illumination. Total daily load profile is illustrated in figure 1. Demand is low during the (00:00 – 5:00 hrs) period, given that the local population is resting during this time. The profile shows an increase in demand between 05:00 a 7:00 am due to the population is getting ready to go to school or their jobs. The rest of the day presents a slight decrease in energy consumption and maintains this energy flow until approximately 16:00 hrs. After 16:00 there is a considerable increase in load demand, with its peak being around 19:00 to 21:00 due to most villagers being awake and present at their households. Finally, the load starts diminishing as the resting hours start getting closer. The data shows that the community presents a total daily load plaint of 109 kWh, with a 10 kW power peak and a mean of 4.54 kW.

![Daily Profile](image)

**Figure 1.** Total daily load profile of the rural community.

2.2. Solar Resource and Temperature
To determine the PV power output, both the temperature in the zone and the solar radiation are required like critical reference. The HOMER software requires an average horizontal global monthly radiation and on-site temperature as input parameters.

Solar radiation and on-site temperature on the selected location (Latitude 1 ° 46.9 'S, Longitude 78 ° 42.3'W) which were obtained on the NASA website [13] are detailed bellow.

The figures of the radiation index and solar clearness for the rural community are given at figure 2. Median solar radiation per year is 4.48 kWh/m² per day, also the highest value radiation is 4.7 kWh/m² per day is registered in November and the lowest valuer radiation 4,23 kWh/m² per day registered within June. With these parameters, it is established that the solar radiation quantity in the area is quite high, which makes Solar energy an attractive alternative.
Figure 2. Clearance indication and mean solar global radiation at month of rural Community.

The surrounding temperature presents itself as a critical parameter for determining the efficiency of PV cells. Hence, surrounding temperature must have a precise measurement. Figure 3 gives details in mean ambient temperature of this area by month. Winter season shows that it's higher temperature at: 11.43 °C in April, and summer season shows that its higher temperature is at: 9.7 °C in July.

Figure 3. Mean temperature at month of the rural community.

2.3. Proposed Hybrid structure description
In the hybrid system shown in figure 4, the components such as: PV panels and Battery bank are by a direct route attached to the DC bar, while Diesel Generator is brought together to the AC bar. The DC/AC converter interconnects the AC and DC bars.
2.3.1. Photovoltaic Panel. Given the location conditions, Solar resource is abundant, which is why PV panels from the HOMER commercial catalog are used. The LONGI SOLAR LR36 is selected with a nominal capacity of 0.370 KW, with an initial cost of 180$, replacement cost of 180$, an efficiency of 19.1%, Operation and Maintenance at 10$ per year.

2.3.2. Diesel Generator. Hybrid systems usually work with a Diesel generator as a backup unit in front of unexpected energy production reduction or a sudden increase in demand. [14]. In this system, the optimal choice is a diesel generator, it has a rated Power of 10 kW, Operation life of 15000 Hours, minimum load ratio of 25%, beginning cost of $ 5000, Operation and maintenance costs set at $ 0.3 per hour, Diesel price is set at $ 0.40 per liter and replacement cost of $ 5000.

2.3.3. Battery bank. The battery size is considered as one of indispensable components in hybrid systems, this is due to their main purpose is to lower the Renewable energy generation’s intermittence [14 -16]. In this simulation, Battery models commonly available are used, such as the Discover AES (24Vdc, 100 Ah, 2.64 kWh). Each battery possesses price initial of $840, O & M cost of $ 10 annual and replacing cost of $ 840.

2.3.4. DC/AC Converter. An electronic converter unit is necessary on a system in which DC components are being used to supply an AC load or vice versa. Initial cost is set at $ 672 and so is replacement cost. O&M cost is $ 10 annual. And it has a 15-year life cycle expectancy with a 90% efficiency.

2.4. Dispatch strategies
Performing an optimal load dispatch on a hybrid system supposes a technical challenge in which the controller set to control the hybrid system must comply with load requirements. The set of constraints that dictate the behaviour of generators and batteries is known as load dispatch [17].

For this system, three dispatch strategies are considered: Load Following, Cycle Charging and Combined Method. Establishing the optimal dispatch strategy follows a set of constraints, which include Generator sizing, Fuel price, Battery quantity, operation and maintenance cost, to name a few. HOMER software simulates the three strategies, and the result is taken to make the optimal system evaluation.

2.4.1. Load Following (LF). In this load dispatch strategy, every time a Generator is required, it then provides enough but no more than the necessary energy to satisfy the load. This control is mostly used when there are a lot of available renewable resources that are normally above the load [18].

Figure 4. Proposed hybrid system
2.4.2. **Cycle Charging (CC).** In this load dispatch method, the energy supplier functions at its entire capacity in order to meet the demand, and surplus energy produced is then used to fill up the batteries. This strategy is better used when renewable energy resource is scarce. This ensures the battery uses less charge cycles to improve battery life, delaying time needed for battery replacement [19].

**Combined Dispatch (CD).** In Combined Dispatch strategy the controller decides whether to use LF or CC depending on the system’s conditions. This controller uses the CC strategy when the present time demand is small, oppositely when the demand is on a high degree, the controller uses the Load Following method [20].

section IV Draws the conclusions.

3. **Results and discussion**

For this hybrid system the simulation is performed using the HOMER software. Optimal dimensioning values are calculated for each dispatch strategy, which allows the comparison of critical data such as: NPC, COE and O&M. The strategies used in this article show innovative results. The simulation was optimized using the following parameters an yearly discount rate of 7.84 % and a 25 year project duration of life. Furthermore, it was considered a 2% as maximum capacity shortage for a get better confiability.

Table 1 gives the differentiation in NPC, Capital, COE and O&M, to different dispatch control in case study. The NPC and COE costs are more economics for CD strategy as sample $ 90,073.10 and 0.2106 $/kWh respectively and the high-cost for LF strategy as 109,319.9 $ and 0.2549 $/kWh respectively. The CD strategy presented a capital cost of $ 21,208, the lowest of all, followed by the CC strategy $ 25,474. The LF strategy obtained a capital cost of $ 54,174.68, because the size of the renewables is the highest. The LF strategy present the O&M cost and CO2 emission lowest 5,096.89 $/yr. and 7,292 Kg/yr. respectively, making more environmentally friendly, but with a high NPC cost.

| Homer Controller          | NPC ($)   | Initial Capital ($) | COE ($/kWh) | O&M ($/year) |
|---------------------------|-----------|---------------------|-------------|--------------|
| Cycle Charging (CC)       | 91,953    | 25,474              | 0.214       | 6,144        |
| Load Following (LF)       | 109,319.90| 54,174.68           | 0.2549      | 5,096.89     |
| Combined Dispatch (CD)    | 90,073.10 | 21,208              | 0.2106      | 6,365.01     |

The size of each component of the hybrid structure is compared and details in table 2. Under the same loading profile, a clear difference in the size of all the components is appreciated. Depending on the different control strategies, the optimal size of PV, converter and battery are different from each other, except for the diesel generator, which will be a fixed size of 10kW.

In LF strategy, the Battery size is extremely high, its capacity is about 86.8 MW. Due the power produced from PV fully satisfy the load. Thus, to lay up the overage energy requires a bigger storage for later use.

| Dispatch Strategies | PV (KW) | Diesel Generator (KW) | Battery (kW-h) | Converter Size (KW) | Load Profile |
|---------------------|---------|-----------------------|----------------|---------------------|--------------|
| Cycle Charging      | 18.1    | 10                    | 33.6           | 7.2                 | kWh/d        |
In the LF strategy, an outstanding use of the renewable source (solar radiation) can contribute with an approximate 89% of annual energy production, the highest standard contrasted to the CC and CD strategies. The renewable component (PV) creates a greater dependence on the hybrid system compared to the other strategies CC (48.4%) and CD (42.4%). The contribution of energy by the Diesel generator in the CC, LF and CD strategies were 51.6%, 11% and 57.6%, respectively. Figure 5 shows the annual electrical energy production of the three dispatch strategies.

**Figure 5.** Annual electric production comparison by source under different dispatch strategies

In terms of pollution, Diesel consumption has a negative effect on harmful to human health and the environment, since various way of polluting agent are being throwing throughout the operation. These discharges contain residue as carbon monoxide (CO) and carbon dioxide (CO2). In addition to other polluting gasses are details shown in table 3.

A hybrid energy source has positive effects on the environment [21]. The combination of photovoltaic energy with diesel and batteries is capable of significantly minimizing emissions. Annual emission releases for HES have been defined and demonstrated under different control tactics to contrast cases from an environmental perspective. In the table 3, it details the emissions produced by the hybrid configuration (PV / diesel / battery) employing LF, CC and CD strategies.

**Table 3.** Dispatch strategies and the pollution produced.

| Quantity (Kg/yr.) | CC   | LF   | CD   |
|-------------------|------|------|------|
| Carbon Dioxide    | 22,154 | 7,292 | 24,438 |
| Carbon Monoxide   | 168  | 55.2 | 185  |
| Unburned Hydrocarbons | 6.11 | 2.01 | 6.74  |
The system with LF has been the biggest environmentally amiable alternative for bring about the lowest proportion of CO2 release (7,292 kg/yr.), in contradiction to the configuration that employs DC strategy, whose had CO2 expulsion is 24,438 kg /yr. Although this system is not the most economical since NPC and Capital cost high as shown in table 1.

In figure 6, we can observe the state of charge of the batteries. This indicates that the CC strategy can store a greater amount of energy with respect to the LF and DC strategies, because the diesel generator works at its greatest range to satisfy the user requirements, relegating the batteries only for emergencies. The state of charge in the DC strategy is the lowest because the diesel generator, the solar panels and the batteries are continuously feeding the load.

![Batteries State of Charge - Monthly Averages](image)

**Figure 6.** Batteries State of Charge - Monthly Averages

4. Conclusions

Optimization of load dispatch strategies is essential in evaluating the feasibility of hybrid energy systems. For this study, three different control strategies were used such as: Cycle charging (CC), Load following (LF) and combined dispatch (CD). HOMER platform was employed to estimate the general study, which includes the sizing optimization and sensitivity analysis. The microgrid proposed has a PV system, battery bank, a DC / AC converter, and a Diesel generator for a rural community in Ecuador.

According to the cost evaluation, the outcome details that the mix of 15.7 kW Photovoltaic Panels, 8 batteries, a diesel generator with 10 kW, and 8.19 kW power converters controlled by the CD method is the most favourable solution. since it has the lowest cost NPC ($ 90,073.10), capital cost ($ 21,208) and a COE ($ 0.2106 / kWh) which were 2% and 17.6% cheaper than the systems with CC and LF strategies, respectively. However, the type of load and the future increase in demand could vary the performance of the hybrid system. This study plays an important function in decision making that leads to superior energy administration methods. By decreasing the Shortage of Capacity by 2%, the size of the system will be greater resulting in a higher cost of energy.

5. References

[1] Rishi K S, Shivraman M, Sukumar M 2018 Power management and economic load dispatch-based control of hybrid pv-battery-diesel standalone ac system *IEEE Access*
[2] Patarau T, Petreus D, Etz R, Lazar E 2018 Techno-economic feasibility study on an off-grid renewable energy microgrid for an isolated greenhouse in Romania IEEE Access

[3] Santillán-Lemus F D, Hertwin M P, Aguilar-Mejía O 2019 Optimal economic dispatch in microgrids with renewable energy sources Energies

[4] Sajjad A, Mazhar A, Elena G 2018 Optimal energy management for off-grid hybrid system using hybrid optimization technique IEEE Access

[5] Toopshekan A, Yousefi H, Astaraei F R 2020 Technical, economic, and performance analysis of a hybrid energy J. Energy

[6] Sifakis N, Konidakis S, Tsoutsos T 2021 Hybrid renewable energy system optimum design and smart dispatch for nearly zero energy ports J. Cleaner Prod

[7] Liu K, Zhang Q, Tian B, Li W, Xuan W, Zhang F, Li J 2016 The Research on an Optimal Dispatch Model of Micro-Grid

[8] Kusakana K 2016 Energy dispatching of an isolated diesel-battery hybrid power system IEEE Access

[9] Jiaxin L, Weijun W, Yingchao Z, Sheng Y 2017 Techno-economic feasibility of pv-wind-diesel-battery hybrid energy system in a remote island in the south China sea AMSE J.

[10] Liu X, Du Z, Yan X 2016 The optimal sizing for ac/dc hybrid stand-alone microgrid based on energy dispatch strategy IEEE Power Energy Technol. Syst. J.

[11] Seaseung O, Suyong C, Jason N, Jongbok B, Marvin C 2017 Efficient model predictive control strategies for resource management in an islanded microgrid Energies

[12] Diario El Comercio, [Online]. Available: https://www.elcomercio.com/actualidad/negocios/precios-gasolina-combustibles-diesel-ecuador.html. (2021).

[13] Power Data Access Viewer, [Online]. Available: https://power.larc.nasa.gov/data-access-viewer/. (2021).

[14] Lu J, Wang W, Zhang Y, Ye S 2017 Techno-economic feasibility of pv-wind-diesel-battery hybrid IEETA

[15] Oloo F, Molefyane B, Rampokanyo M 2020 Modelling and optimisation studies for generator dispatch strategies for deployment of an off-grid micro-grid in South Africa IEEE-ENERGYCON

[16] Kassa Y, Zhang J, Zheng D 2019 Optimal energy management strategy in microgrids with mixed energy resources and energy storage system IET Journals

[17] Ishraque F, Shezan A, Ali M, Rashid M 2021 Optimization of load dispatch strategies for an island microgrid connected with renewable energy sources Appl. Energy

[18] Arevalo P, Benavides D, Leonardo J, Hernandez L, Jurado F 2020 Optimal energy management strategies to reduce diesel consumption for a hybrid off-grid system Redin - Universidad de Antioquia

[19] Saleh A, Naim M, Rafi M, Ramli M, Mekhilef S 2019 Energy management and optimization of a pv/diesel/battery hybrid energy system using a combined dispatch strategy Sustainability

[20] Shezan A, Hasan K, Datta M 2019 Optimal sizing of an islanded hybrid microgrid considering alternative dispatch strategies Australian University Power Engineering Conference

[21] Fazelpour F, Soltani N, Rosen M 2016 Economic analysis of standalone hybrid energy systems for application in Tehran, Iran Int. J. Hydrogen Energy