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Integrated Energy Supply Configuration for Stand-Alone Island Based on Two-Layer Optimization Algorithm

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***Abstract*—This paper focus on the power supply of the stand-alone island in South China Sea. Considering the infeasibility of connection to the main energy supply system, this paper propose a mathematical model of two-layer optimization to configure the scale of diesel generator, PV, and battery storage. Under the methodology, the island can realize the reliable, economic and environmental-friendly power supply.**

***Keywords*—integrated energy; stand-alone island; two-layer optimization; energy storage**

I. INTRODUCTION

There are various stand-alone islands distributed in South China, existing potential energy demand. Located hundreds of kilometers away from mainland, there is less feasibility to realize the connection between the stand-alone island and main energy system. Consequently, scientific methodology to optimize deployment of integrated energy has been focus on reliability and efficiency.

Several papers [2]~[5] have made contribution to the mathematical model and software application towards the power configuration focus on pure renewable energy system. However, for the stand-alone islands holding the limitation of renewable construction, different ratio of controllable generation plants and furthermore multi-scheme comparison should be taken into consideration.

This paper focus on the integrated power consideration of stand-alone fisherman island. Basing on the hourly energy demand and renewable resource talent, this paper applies two-layer optimization algorithm, with the comparison of multi-scheme of renewable and storage under different ratio of diesel generation, typical combination will be exhibited to guide the work in reality.

II. METHODOLOGY MODELING OF TWO-LAYER OPTIMIZATION

Objective of modeling of the optimization is to realize the minimum of NPC under the scope of whole society considering the penalty of carbon emission, which is as follows.

$$C_{NPC}=\sum_{1}^{T}(C_{inv}^{i}+\sum_{1}^{T}\left(C_{O}^{i}(t)+C_{M}^{i}(t)-S_{i}(t)\right)\cdot PV_{t}) \tag{1}$$

For the operation of integrated energy system in each time interval, besides the fossil resource cost, storage depreciation, this paper will take the environmental factor into consideration. Penalty of carbon emission is added into the operation cost, which is shown as follows. As shown below, $B_{cost}^{ch,dis}(t)$ indicates the depreciation in Δt interval, which is determined by the investment and lifecycle of selected battery. α Indicates the penalty of carbon emission.

$$C_{op}=\sum_{1}^{T}\left\{B_{cost}^{ch,dis}(t)+GEN_{cost}(t)+\alpha\cdot P_{CO_2}\right\} \tag{2}$$

In the modeling of the optimization, the scale of the power supply unit can be regarded as the top level, which is marked as P_{pv}, N_{wt}, Q. In which capacity of PV and wind units can be regarded as discrete variables, and capacity of energy storage can be regarded as continuous variable. Top-Level model is shown as follows.

$$S_1=\min C_{NPC}$$
$$s.t.\begin{cases}0\le P_{pv}\le P_{pv-\max}\\0\le N_{wt}\le N_{\mathrm{wt-max}}\\0\le Q\le Q_{\max}\end{cases} \tag{3}$$

The bottom decision variable Z should be related to the top variable, which is the power output of each power unit, i.e. the output of PV, wind and energy storage. Main objective of bottom is to reach the minimum of operation and maintenance cost, which is a linear optimization question.

$$S_2 = \min(C_{OP} + C_M)$$
$$s.t.\begin{cases} 0 \le G(t) \le G_{\max} \\ SOC_{\min} < SOC(t) < SOC_{\max} \\ SOC(t) = SOC(t-\Delta t) + p_{\text{charge}}(t) - p_{\text{discharge}}(t) \\ 0 \le p_{\text{ch/dis}}(t) \le P_{\text{ch/dis-max}} \\ p_{elec}(t) = \sum G(t) + p_{\text{charge}}(t) - p_{\text{discharge}}(t) \end{cases} \quad (4)$$

III. CASE ANALYSIS

A. Electric Demand & Renewable Talent

In this sector, a stand-alone island (Marked as FLA) for fisherman with the peak demand of 40kW is applied as the case for analysis. In which, the base load is about 20kW to supply resident office, the load over 20kW is for fishers, which can be shifted to other time period. In addition, with the relative stable climate, the peak/average load is similar in each months as follows.

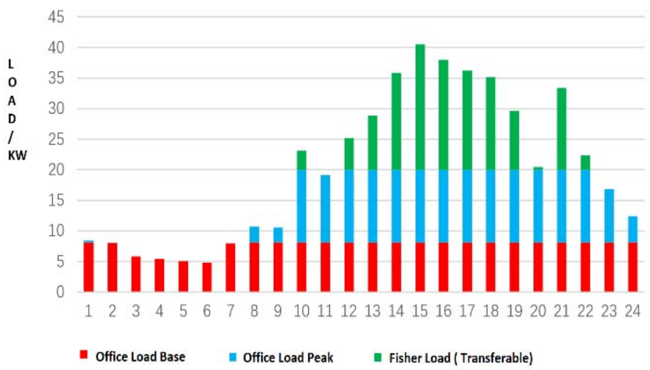


FIGURE I. HOURLY ELECTRIC DEMAND CURVE OF FLA ISLAND

Located in tropical area, FIA island is great talented with renewable energy. According to the NASA statistics, the illumination intensity is above 5.5kWh/m2/d except for winter in several months. With the simulation of 1kWh PV unit, the average generating equipment availability hour can reach to 1600 hours, which performs a great utilization. As to the wind resource, the maximum wind speed appears at November and December about 10m/s. Considering the potential typhoon in tropical area, concentrated wind turbine is not proposed in this paper.

B. Optimization Input Parameter

Under the electric load characteristic and abundant renewable resources. Three modes of power supplying will be considered as different schemes, and the input parameter of two-layer optimization is shown as follows.

Pure Renewable: Energy demand is completely-supplied by renewable energy, with storage to reduce the abandonment of PV and wind.

Partly Diesel: Important energy demand is supplied by diesel generation, with PV and storage to cover the shift able load.

Diesel Covering: The capacity of diesel covers the peak demand, with PV as a supplement to reduce carbon emission.

For the selection of battery storage, Lithium Iron Phosphate Battery is proposed. On one hand, to prevent the emergency from calling frequency collapse, power mode battery is more appropriate for the stand-alone power system. On the other hand, based on the operation experience, attenuation of lead carbon battery is usually obviously faster with the real life of 4~5 years, to reduce the replacement cost of transportation, Lithium with longer cycling times is recommended.

TABLE I. INPUT PARAMETER OF TWO-LAYER OPTIMIZATION

Parameter	***Unit***	***Value***
Diesel Generation Investment	RMB/kW	1500
PV construction unit price	RMB/kW	7000
Energy Storage unit price	RMB/kW	4000
Carbon Emission Penalty	RMB/t	40
Discount Rate	%	10
Diesel Price	RMB/t	5600

C. Multi-Scheme Configuration

As mentioned above, in different power supply scheme, the configuration is as follows. Scheme 1 considers the intermittent of renewable energy, to meet the power supply for each time interval, PV capacity goes to 157kW facing the risk of abandonment of resource; Scheme 3 configures adequate diesel plant to meet the peak demand, power storage is not deployed due to the relatively high investment and short life period.

TABLE II. POWER CONFIGURATION OF RENEWABLE AND STORAGE IN EACH SCHEME

Item	**Scheme 1 (kW)**	**Scheme 2 (kW)**	**Scheme 3 (kW)**
PV	157	30	10
Wind	50	12	6
Storage	225	0	0
Diesel	0	20	40
Controllable	*0*	*50%*	*100%*

IV. SCHEME COMPARISON

A. Operation Comparison

Table 1 shows the overall operation performance of the systems in each scheme. As to the operation performance of each Schemes.

A pure renewable/battery system is proposed in Scheme, in which 100% of power is produce by PV and Wind Turbine without air pollution. However, in order to guarantee the power system, redundant PV scale will cause 60% of Solar Abandon, which will raise the investment significantly.

Diesel Generation is applied in Scheme 2 and Scheme 3. In Scheme 2, diesel generation supply the basic power demand, with relatively more renewable unit to raise the environmental index than Scheme3. Under less utilization of fossil resource, the carbon emission per year is about 73.3t , less than 125.0t in Scheme 3.

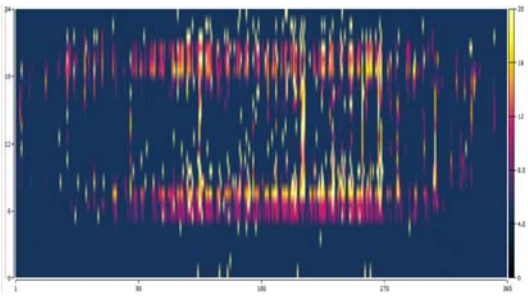
TABLE III. SYSTEM OPERATION INDEX IN EACH SCHEME UNDER SCHEDULE OPTIMIZATION

Item	Scheme 1	Scheme 2	Scheme 3
Carbon	0.0	73.3	125.0
SO_2	0.0	0.2	0.3
NO_x	0.0	0.6	1.1
Utility	100.0%	31.0%	30.6%
Renewable	100%	50.3%	15%
Solar Abandon	60%	5%	0%

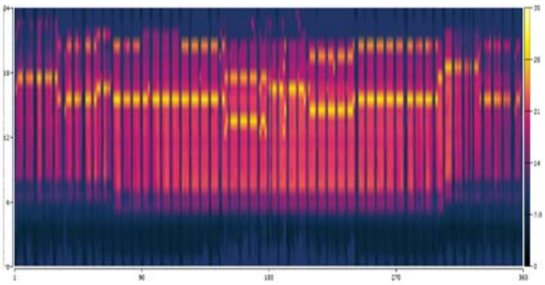
Comparison Analysis of operation for scheme 2 and scheme 3 in shown as follows.

In scheme 2, with partially deployment of diesel generator. At the time between 8 a.m. to 16 p.m. PV can play as the main power support to reduce the cost of fossil energy, diesel generators shut down to prevent from low-efficiency operation. As shown in the black area as follows. Within the time no sunlight, diesel energy plays as the base energy with the wind and battery storage as supplement.

In scheme 3, diesel energy can cover the peak demand of energy. To realize the economical operation range, the compatibility of PV and wind is obviously limited, which will improve the cost of emission.



(a) Diesel Genertaion in Scheme 2



(b)Diesel Genertaion in Scheme 3

FIGURE II. POWER CONFIGURATION OF RENEWABLE AND STORAGE IN EACH SCHEME

B. *Economical Comparison*

With the application of the method above, FLA come up with the optimization result as follows. In different boundary circumstances of diesel scale, in scheme 1, under the redundant deployment of battery and renewable resource, economic index is worst in all the cases. In Scheme 2 and Scheme 3, Scheme 2 configures with more renewable energy which will improve the investment. However, with less cost in diesel cost, Scheme 2 is more economical than Scheme 3, even the calculation doesn’t take carbon emission penalty into consideration.

As a conclusion, when the diesel scale covers 50% of the load, the system performs the most economical operation.

C. *Recommended Supply Mode*

According to the analysis of operation and economic performance above, the conclusion of power figuration is as follows:

Pure Renewable: If this mode is applied, integrated energy system can raise best environmental index. However, considering the indeterminacy of solar and wind energy, PV capacity should be over 3 times of peak power demand. Together with the redundant energy storage, this mode performs the worst economical index.

Partly Diesel: Energy system meet the important power demand by controllable energy. With the complementary of solar and wind, renewable can be fully applied. As diesel unit can operate among economical range combining with transferable load, this mode performs best economical index.

Diesel Covering: Cooperating with transferable load and PV unit, diesel can operate smoothly among economical range. As the relatively high cost of diesel resources, this mode gets the most pollution, NPC is relatively higher than partly mode.

Consequently, for FIA island, this paper recommend the partly diesel mode, with 20kW diesel generator, 30kWp PV unit and 12kW wind turbine. Considering the high cost of energy storage, basic situation proposes the cooperation with PV and transferable load as substitution of storage. The next sector will take a sensitivity analysis under the decreasing the investment of battery.

V. CONCLUSION

Located far away from the main energy system, the reliability and economic performance is the focus of the energy supply system. This paper propose a modeling of two-layer optimization, under the precise analysis on hourly energy balance, the methodology can come up with an economical and environmental configuration. With the decrease of cost of battery, the ratio of renewable energy will increase to reduce the carbon emission.

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