

The Influence of Energy Storage Systems on Emissions Reduction in Power Generation Systems based on Dual Optimization Methods

Abstract. This paper investigates methods to find out the effects of energy storage systems on economic emissions scheduling in power plants (ESS for EES). ESS for EES can assist in scheduling generator operations by considering fuel costs, emission levels, energy storage systems while still meeting load demands and operational constraints so that the optimal results are obtained. In this article, the ESS problem for EES is formulated as a multi-objective problem by considering the fuel costs and emissions objectives of the generating units.

Streszczenie. W artykule zbadano wpływu systemów magazynowania energii na ekonomiczne planowanie emisji w elektrowniach (ESS dla EES). ESS dla EES może pomóc w planowaniu pracy generatora, biorąc pod uwagę koszty paliwa, poziomy emisji, systemy magazynowania energii, jednocześnie spełniając wymagania obciążenia i ograniczenia operacyjne, aby uzyskać optymalne wyniki. W tym artykule problem ESS dla EES został sformułowany jako problem wielozadaniowy, biorąc pod uwagę cele w zakresie kosztów paliwa i emisji jednostek wytwórczych. (**Wpływu systemów magazynowania energii na ekonomiczne planowanie emisji w elektrowniach**)

Keywords: Emissions, Energy Storage System, Economic Dispatch, Genetic Algorithm, Ant Lion Optimizer

Słowa kluczowe: Emisje, system magazynowania energii, wysyłka ekonomiczna, Genetic Algorithm, Ant Lion Optimizer

Introduction

Electricity plays an important role in human life and has a large influence on air pollution. Furthermore, industrialization and population growth are the first factors for regular increasing electricity consumption [1]. Population growth has the effect of causing high demand for electrical energy, thereby contributing to increasing carbon dioxide content from year by year. If the number of thermal power plants which are generally fossil fueled such as coal, oil and gas increase, the carbon dioxide emissions that are wasted into the atmosphere also increase, resulting in more losses to humans and the surrounding environment. In addition, it can cause global warming which is an important issue in many countries in the world [2-4].

Energy storage now is also an important part of the increasingly widespread of renewable energy. With the massive growth of renewable energy sources, energy storage can play an important role in the integration of renewable energy. This is especially useful in improving the quality of electric power, as well as better network dependency and stability [5, 6]. Thus, it can help reduce emissions hazards [7].

One strategy to reduce the amount of emissions generated by power plants is with economic emission scheduling (EES). EES is a way to schedule optimal power generation of a generating unit to meet the electricity loads demand and also to minimize pollutant emissions generated by the generating unit [8]. Many research has been done in the field of EES. Several researchers have discussed about ESS but have not integrated together ESS and renewable energy yet. Authors in [9] analyzed how to minimize fuel costs and emissions simultaneously from power plants to meet power demand in linear and nonlinear systems. In [10], combined economic emission dispatch problem was solved using adaptive wind driven optimization (AWDO) method. Whale Optimization Algorithm (WOA) was proposed for economic and emission dispatch for optimal results in [11]. Paper [12] analyzes ant lion optimizer for optimal scheduling of thermal units for small scale electrical economic power dispatch problems. In the research mentioned above, none of them considered the integration of renewable energy generation and energy storage systems. Furthermore, at present, renewable energy generation and energy storage systems have evolved so that the authors are interested in conducting research in the

case of economic emissions in electric power systems with energy storage systems. Therefore, there is a need for research that investigate economic emission dispatch of power plants to meet load demands that integrate renewable energy generation and energy storage systems to determine opportunities for suppressing plant emission so that the environment is maintained.

Literature Review

a. Economic Emission Scheduling (EES)

In order for the power plants to produce electricity as economically as possible, economic scheduling is needed according to the plant is requirements plus the amount of transmission losses [13-15]. Each plant has its own characteristics represented by the cost equation. Similar to the exhaust gas from a thermal generator, each generator has its own exhaust gas characteristics. For cost and emission characteristics, there are minimum and maximum limits of generating operations. Various mathematical methods and optimization techniques have been employed to solve for ELD problems [16] where for solve the problem of economic dispatch, there are two approaches, including classical and meta-heuristic methods [17], such as ant lion optimizer and genetic algorithm.

Optimization of generator costs to minimize total fuel costs can be written as follows [18],

$$(1) C_i P_i = \sum_{i=1}^n \alpha_i P_i^2 + \beta_i P_i + \gamma_i$$

Where α , β and γ are the fuel cost coefficients of each generator, P is the power output of the generator, n is the total number of generators allocated in the system, and $C_i P_i$ is the operation cost of each generator unit. As for the optimization of emissions to minimize total emissions, the function is explained as follows,

$$(2) E_i P_i = \sum_{i=1}^n \delta_i P_i^2 + \varepsilon_i P_i + \zeta_i$$

Where δ , ε , and ζ are the fossil emission coefficients of each generator, P is the output of the generator, n is the total number of generators allocated in the system, and $E_i P_i$ is the emission of each generator unit.

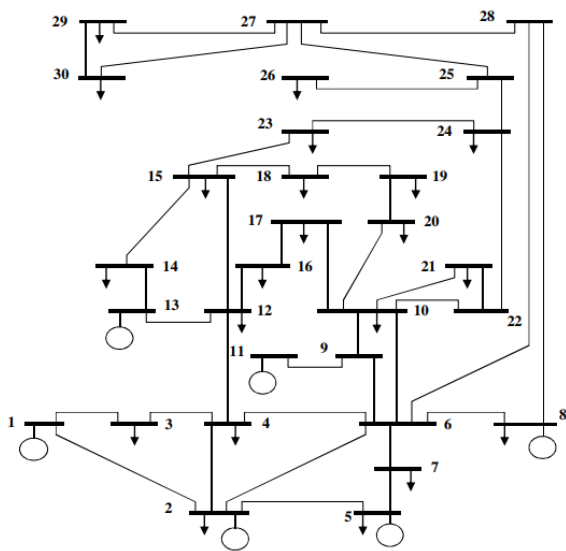


Fig.1. Single line diagram of the IEEE 30-bus power system [19]

In EES, power plant operating characteristics are needed. EES employs power plant operating characteristics to optimize the power output of power plants as needed between maximum and minimum operating limits. In the EES process, there are two constraints that must be considered, namely equality constraints and inequality constraints. The equality constraint is usually in the form of a power balance that is the balance between the total power produced by all power plants which must supply the total power demand plus the total power losses in the network. Then the inequality constraints which are also called the capacity constraints of plants, are the limitation capacity of all generators that is limited by the minimum and maximum power limits [8] as,

$$(3) \quad P_i^{min} \leq P_i \leq P_i^{max}$$

The combination of the generation cost equation with emissions is formulated as follows,

$$(4) \quad \text{Min} (F_T) = \sum_{i=1}^n (\alpha_i P_i^2 + \beta_i P_i + \gamma_i) + (\delta_i P_i^2 + \varepsilon_i P_i + \zeta_i)$$

b. Energy Storage System (ESS) and Renewable Energy (RE)

Energy storage system is a concept of storing some energy that can be retrieved when needed at a time. There are several technologies used in energy storage depending on the purpose of the utilization of energy storage systems. Batteries are one of the most popular materials in

developing the concept of energy storage systems. In this simulation, batteries used have a cost coefficient of 0.0043 \$/kWh with a capability of 300 kWh [20]. Renewable energy is an energy-friendly generating system produced from natural sources such as the sun and wind [21].

Proposed Methodology

a. Ant Lion Optimizer (ALO)

Ant lions are a family of Myrmeleontidae and Neuroptera (winged insects). The life cycle of ant lions includes two main phases: the larval phase and the adult phase. The age of ant lions can reach 3 years and undergo metamorphosis in the cocoon to mature. They mostly hunt when they are larvae and when they grow up they reproduce [22]. The optimization is described as ant lions moving around the search space using different random paths, then random paths are applied to all ant lion dimensions, which end in the ant lion trap. Then the ant lions build a hole that is proportional to its size (the larger the size, the larger the hole) where the larger hole has a higher probability of being captured by the ant lion. Once the antlion realize that an ant is in the trap, it tries to catch it by throwing sands toward to edge of the pit to slide the prey to them [23]

b. Genetic Algorithm (GA)

Genetic Algorithm (GA) is a part of the Evolutionary Algorithm, which is an algorithm that imitates the natural evolutionary process where the main concept is that the most superior individuals will survive, whereas weak individuals will become extinct [24]. GA was developed by John Holland in 1970 and is a global search method based on natural selection [25].

GA is based on natural selection and genetic factors that persist. GA operates with a set of chromosomes, known as populations. This is initialized randomly and then looks for filter and filter solutions and finally blends into the best single solution. This algorithm uses random techniques and information structures to get optimization results. In optimization, the optimal conditions obtained are the main targets to be achieved. But in the optimization algorithm, local optimum conditions often occur. Local optimum is a condition where the algorithm reaches the highest or lowest value on several values. This is contrary to the global optimum conditions, namely the algorithm reaches the highest or lowest value for all candidate solutions in a particular problem [8].

Case Study and Discussions

The power system model used in this study is the IEEE 30 bus power system with 6 generator as shown in Table 1, then it was modified with the addition of renewable energy in the form of wind turbine and ESS using batteries as described in Table 2.

Table 1. The Cost and Emission Coefficient for equation of conventional plants [26]

Generator	α (\$/MW ² h)	β (\$/MWh)	γ (\$/MWh)	δ (kg/MW ²)	ε (kg/MWh)	ζ (kg/h)	P_i^{min} (MW)	P_i^{max} (MW)
1	0.1525	38.54	756.8	0.0042	0.33	13.86	10	125
2	0.106	46.16	451.325	0.0042	0.33	13.86	10	150
3	0.028	40.4	1050	0.0068	-0.5455	40.267	35	225
4	0.0355	38.31	1243.53	0.0068	-0.5455	40.267	35	210
5	0.0211	36.328	1658.57	0.0046	-0.5112	42.9	130	325
6	0.018	38.27	1356.66	0.0046	-0.5112	42.9	125	315

Table 2. The equation of renewable energy costs and ESS

Wind Turbine [27]	$E = 0P^2 + 1436P + 0$	$P_{min} 0 \text{ MW}$
ESS [20]	0.0043\$/kWh for 300kWh	$P_{max} 70 \text{ MW}$ for 300kWh

Case Study 1

In case study 1, a calculation was made by comparing the ant lion optimizer method and genetic algorithm on the IEEE 30 bus power system with 6 generator and 750 MW load demand. The purpose of this case study is to obtain the emission value and network losses value before it is integrated with renewable energy power plants and ESS. The optimization results obtained for optimal emissions per 1 MWh are 0.75 Kg³/h with GA and 0.748 Kg³/h with ALO. As for the optimal network losses results obtained are 0.0293 MW/h with GA and 0.0291 MW/h with ALO. Figure 1 shows the optimization results for economic emission scheduling using ALO and GA for case study 1. The results inform that using ALO are better than using GA.

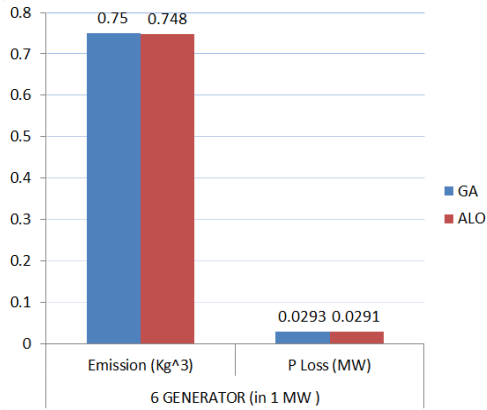


Fig.1. Exhaust gas and network losses comparison using ALO and GA for Case Study 1

Case Study 2

In case study 2, a calculation was made by comparing the ant lion optimizer method and genetic algorithm on the IEEE 30 bus power system with 6 generator and additional of a renewable energy generator with a maximum working setting of 75MW with total load of 750 MW. By integrating renewable energy generation, emissions will go down, although network losses will increase due to the addition of transmission lines which is certainly directly proportional to the increase in the value of network losses. From the simulation results, emissions obtained for every 1 MWh are 0.622 Kg³/h by the GA method and 0.621 Kg³/h by ALO. The network losses are 0.0307 MW/h and 0.0305 MW/h, with the GA and ALO methods, respectively, as can be seen in Fig. 2.

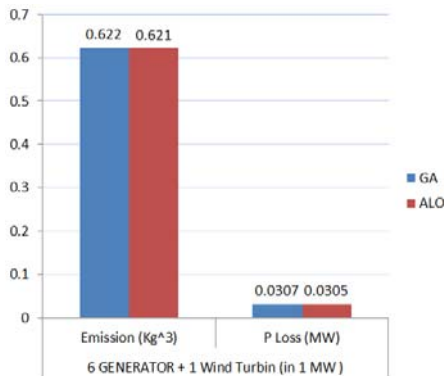


Fig.2. Exhaust gas and network losses comparison using GA and ALO with integrated wind turbine for Case Study 2

Case Study 3

In case study 3, calculations were carried out as in case study 2 but with the addition of a renewable plant with an

optimum working arrangement of 75MW and ESS with a saving capacity of 30MWh and load demand of 750 MW. In this case study 3, the performance of renewable energy generators is modeled 40MW out of 75MW and the remaining work capacity of 30MW is used to fill ESS. For this case 3, the system is designed to work 12 hours of work in the afternoon. From the results obtained, both the emissions and network losses using the ALO method are lower than the results obtained by the GA method. Figure 3 shows the results obtained for case study 3.

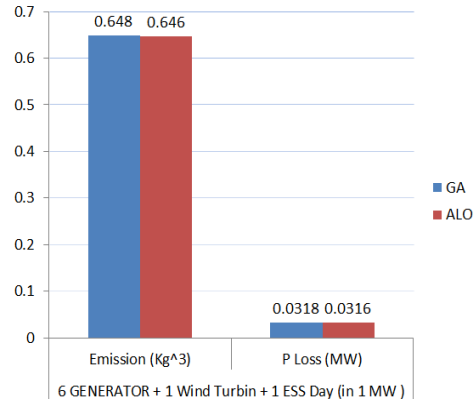


Fig.3. Exhaust gas and network losses comparison using GA and ALO with integrated wind turbine and ESS all day time for Case Study 3

Case Study 4

In case study 4, simulation were made with the addition of a renewable power plant with an optimum working arrangement of 75 MW and ESS with an optimum capability of 30 MW with a demand load of 750 MW. Similarly, the results for this case, shows that the ALO method outperforms the GA method. The results for this case study can be seen in Fig. 4.

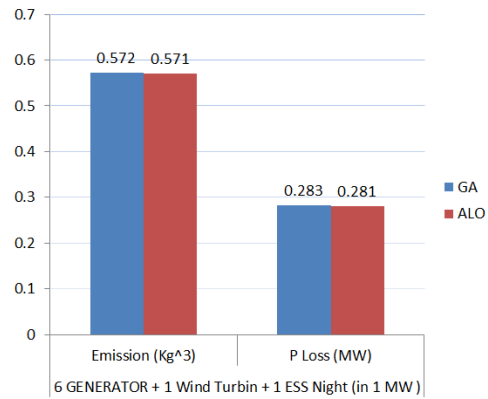


Fig.4. Exhaust gas and network losses comparison using GA and ALO with integrated wind turbine and ESS all night for Case Study 4

Tabel 3. The result parameter variant test system

	GA		ALO	
	Emission (Kg ³)	PLoss (MW)	Emission (Kg ³)	PLoss (MW)
Study Case 1	0.750	0.0293	0.748	0.0291
Study Case 2	0.662	0.0307	0.621	0.0305
Study Case 3	0.648	0.0318	0.646	0.0316
Study Case 4	0.572	0.0283	0.571	0.0281

Conclusions

This research investigates the economic scheduling of power plants to meet the load demands that integrate renewable energy generation and energy storage systems to determine opportunities to reduce plant emissions. In this study, there were 4 case studies conducted by comparing 2 metaheuristic methods, namely the GA method and the ALO method. The four case studies carried out were (1) without renewable energy generation and ESS, (2) with renewable energy generation with a total capacity of 75 MW, (3) one renewable plant with 75MW optimum work arrangements and ESS with 30MWh storage capacity and (4) one a renewable energy generator with an optimum working arrangement of 75 MW and ESS with an optimum capability of 30 MW. The total system load for the four case studies is 750 MW. From the four simulations for each case study, it was found that the ALO method was superior to the GA method in term of lower emissions and network losses.

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Authors: Basim Thariq, Electrical Engineering Study Program, State Polytechnic of Ujung Pandang, Indonesia, E-mail: basim.thq@poliupg.ac.id; Ardiaty Arief, Ph.D, Department of Electrical Engineering, Hasanuddin University, Indonesia, Email: ardiaty@eng.unhas.ac.id; Prof. Dr. Ansar Suyuti, ASEAN.Eng. Department of Electrical Engineering, Hasanuddin University, Indonesia, Email: asuyuti06@yahoo.com.

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