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COMPARATIVE ANALYSIS ECONOMIC LOAD DISPATCH USING RENEWABLE AND NON RENEWABLE ENERGY RESOURCE

Varun kumar[1], Er. Sonal Sood[2]
[1]Research Scholar, Dept. of Electrical & Electronic, USET, Rayat Bahra University
Kvarun864@gmail.com
[2]Assistant Professor, Dept. of Electrical & Electronic, USET, Rayat Bahra University
Sonal.sood@rayatbahrauniversity.edu.in

Abstract

This research paper offers a comparative analysis between renewable (RE) and non-renewable energy (NRE) resources in the context of the economic load dispatch (ELD) problem. The ELD problem refers to efficiently scheduling the power outputs from different sources to meet a system's load demand at the least possible cost, while also adhering to various operational constraints. With the integration of renewables into power grids, due to environmental and sustainability concerns, it has become imperative to understand their technical, environmental, and economic implications vis-a-vis traditional non-renewable resources. Our analysis reveals that while RE sources bring environmental benefits and potential long-term economic advantages, they introduce challenges related to intermittency, forecasting, and grid stability. On the other hand, NRE sources, while offering stability and scalability, present environmental challenges and future economic uncertainties due to finite resources. A synergy of both resources, complemented by advances in energy storage and grid management, is proposed as the most promising pathway for future energy systems.

Keywords: Economic Load Dispatch, Renewable Energy, Non-renewable Energy, Grid Stability, Intermittency, Energy Storage, Forecasting, Environmental Impact, Economic Implications, Power Systems.

1. Introduction

The increasing energy demand coupled with rising environmental concerns has necessitated the integration of renewable energy (RE) sources like solar, wind, hydro, biomass, etc. into existing power grids. However, the intermittency and variability associated with RE present significant challenges to power system operation and control. On the other hand, traditional non-renewable energy (NRE) sources like coal, natural gas, nuclear, etc., while providing stable and controllable output, have adverse environmental impacts and uncertain long-term availability and costs.

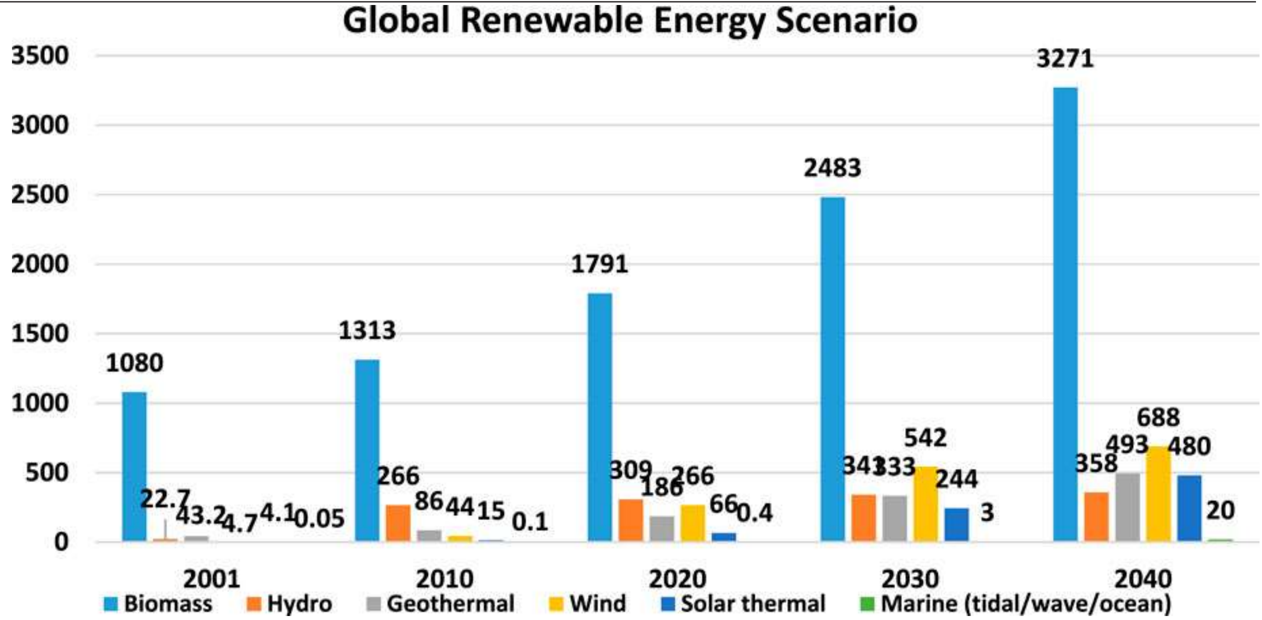

Fig 1 Global renewable energy scenario by 2040

In this context, this paper presents a comparative analysis between RE and NRE within the economic load dispatch (ELD) framework. ELD refers to the short-term determination of optimal power generation levels for the online generators in a power system to meet the load demand at minimum operating cost while satisfying various network and operational constraints [1]. ELD serves as an important decision-making tool for cost-effective operations of modern power grids.

The integration of RE resources impacts various aspects of ELD including cost modeling, stability considerations, and environmental constraints [2]. The intermittency and variability factors also necessitate forecasting of RE power generation for integrating them into ELD. On the other hand, NRE sources provide stable and dispatchable power but at higher operating costs and environmental impacts.

Through a comprehensive literature review and comparative analyses on technical, economic and environmental performance, this paper provides useful insights into the synergistic utilization of both RE and NRE within the ELD framework for sustainable and affordable power generation.

Overview of Economic Load Dispatch

Economic load dispatch aims to schedule the power generation levels of online generators economically while meeting the total load demand and operational limits. The total cost of generation is minimized while satisfying the power balance and generator capacity constraints.

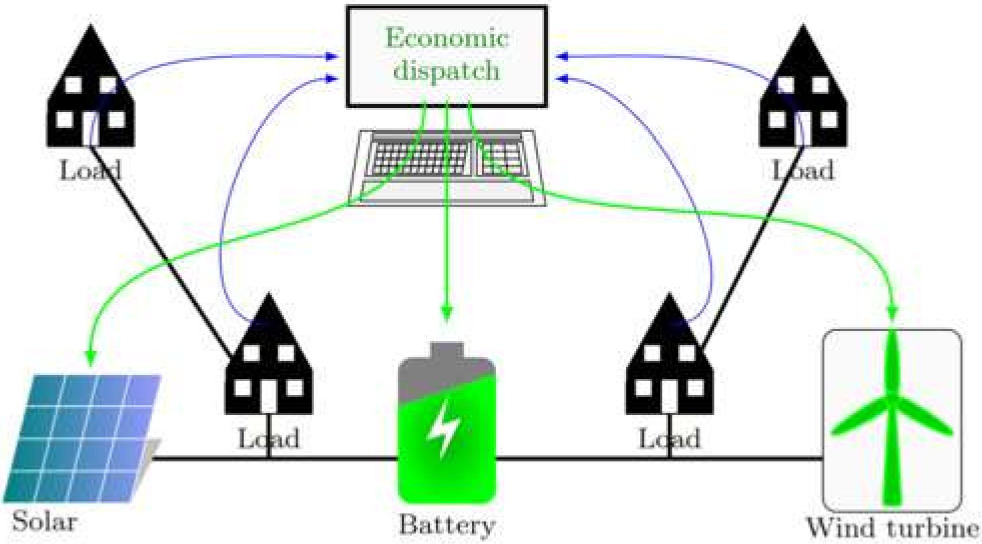

Fig 2 Load Dispatch Model

Mathematically, the ELD problem is formulated as [3]:

Minimize: $F(PG) = \sum ni=1\ fi(PGi)$ (1)

Subject to:

Power balance constraint: $\sum ni=1\ PGi = PD + PL$ (2)

Generator capacity limits: $PGi(min) \leq PGi \leq PGi(max)$ (3)

Where,

F = Total generation cost ($/hr)

fi = Cost function of generator i ($/hr)

PGi = Power generated by unit i (MW)

PD = Total power demand (MW)

PL = Total transmission losses (MW)

n = Number of online generators

The generator cost functions are modeled as quadratic polynomials as:

$fi(PGi) = aiPGi2 + biPGi + ci$ (4)

Where ai, bi, and ci are the cost coefficients of generator i.

The constraints make ELD a complex optimization problem solved using various mathematical programming and heuristic techniques like lambda-iteration, gradient methods, evolutionary algorithms, artificial intelligence, etc. [4].

ELD provides the least-cost dispatch while respecting the operational limits of the generators and power balance. With increasing RE penetration, additional constraints are imposed to account for the intermittency and uncertainty factors.

Impact of Renewable Energy Integration on ELD

The integration of renewable resources like solar, wind, small hydro, etc. into power system operations has posed significant challenges to the ELD problem [5], [6]:

- Uncertainty and Intermittency: The variable and intermittent nature of RE generation makes it difficult to accurately estimate the power availability. This necessitates forecasting of RE power for integrating into ELD.
- Zero marginal cost: RE sources like solar and wind have negligible operating costs compared to conventional generators. This distorts the economic dispatch priorities.
- Grid stability: RE sources being interfaced through power electronic converters do not contribute to system inertia and stability. This necessitates additional reserves and operating constraints.
- Transmission constraints: RE plants are often remotely located requiring additional transmission infrastructure. The variability in RE may cause congestion and bottlenecks.
- Environmental constraints: Higher RE penetration allows reduced emissions. However, this requires evolving environmental dispatch models in ELD.

These factors necessitate modifications in the mathematical modeling and solution techniques for the ELD problem under high RE penetration scenarios. The objective function and constraints need to appropriately incorporate the RE sources and their uncertainties. Key focus areas include RE forecasting, reserve determination, storage coordination, and environmental dispatch [7].

RE Forecasting

RE forecasting predicts the power generation from solar, wind, etc. over different time horizons to accommodate their variability and uncertainty. Short-term forecasting (minutes to hours ahead) is important for real-time dispatch including ELD. Long-term forecasts are needed for maintenance scheduling, fuel allocation, etc.

Various statistical and artificial intelligence techniques like autoregressive models, neural networks, support vector machines, etc. are used for RE forecasting [8]. Ensemble forecasting combining outputs from multiple models improves accuracy. Updating forecasts with real-time telemetry and measurements also enhances dispatchability.

Accurate forecasting enables the integration of RE into ELD by continuously updating the RE generation limits (PGi(min) and PGi(max)) in (3). The forecasts are also used to determine the additional reserves required to balance RE variability.

Reserves for Grid Stability

RE sources do not inherently provide inertia and grid stabilizing characteristics offered by synchronous generators [9]. This necessitates procurement of additional operating reserves to ensure stability and balance supply-demand dynamics caused by sudden RE fluctuations.

Deterministic and probabilistic approaches are used to quantify the additional reserves required under different RE penetration scenarios [10]. Co-optimization techniques consider reserve allocation within the ELD formulation itself to minimize total cost. Fast-responding storage technologies like batteries also help provide reserves for stable grid operation.

Energy Storage Coordination

Energy storage technologies like pumped hydro, compressed air, batteries, etc., provide an effective means to mitigate the variability of RE generation [11]. Charging storage when RE output is high and discharging when it is low helps smooth out fluctuations.

Joint optimization of storage and RE within ELD provides a least-cost dispatch solution. The storage dynamics such as state of charge, charging/discharging limits, and efficiencies are incorporated as additional constraints in the ELD model. Advanced storage coordination strategies further help in reducing the system operating costs and RE curtailments.

Environmental Dispatch

Higher RE penetration in the generation mix allows reduced emission levels. However, this requires the emission characteristics to be incorporated within the ELD optimization [12]. Environmental dispatch models aim to minimize not just cost but emissions as well through multi-objective formulations.

Key emissions considered include CO2, SO2, NOx, and particulate matter from fossil-fuel generators. Various techniques like weighted sum method, goal programming, and evolutionary algorithms are used to solve the multi-objective environmental dispatch problem. A right tradeoff between cost and emissions is essential for sustainable ELD.

Thus, RE integration requires enhanced RE forecasting, stability considerations, storage coordination, and environmental dispatch – necessitating more complex ELD formulations compared to conventional models.

Non-Renewable Energy Resources

Non-renewable energy (NRE) sources like coal, natural gas, nuclear, and oil have traditionally dominated power generation owing to their controllability, reliability, and economies of scale. The key characteristics of conventional NRE technologies are as follows [13]:

- Stable and controllable output: NRE generators provide flexible, dispatchable power by varying their outputs within seconds to meet changing demands. This enables reliable grid operation.
- Higher capacity factors: Capacity factors of NRE plants are typically above 50%, enabling maximum utilization of installed capacity, unlike the lower capacity factors of most RE sources.
- Economies of scale: The high unit capacities of NRE plants, typically in hundreds of megawatts, allow exploiting economies of scale in construction and operation.
- Lower land requirement: The high energy density of NRE sources allows compact siting unlike RE projects which require large land areas.
- Ancillary services: Synchronous NRE generators contribute to grid inertia, voltage control and power system stability.
- Seasonal availability: NRE availability is independent of weather conditions and seasons, thus providing consistent year-round generation.

These benefits explain the dominance of conventional NRE plants in power generation worldwide. However, NRE technologies also have certain limitations and challenges:

- Emissions: NRE plants are a major source of air pollutants and carbon emissions contributing to climate change and environmental concerns.
- Water consumption: Thermal power plants utilize large volumes of water for cooling purposes, often straining local water resources.
- Long-term fuel availability: NRE depends on finite fossil fuel resources whose costs are also prone to volatility based on geo-political factors.
- Safety: Concerns related to plant safety and radioactive waste exist for nuclear power.
- Capital costs: While levelized costs are reasonable, the capital costs for building large NRE plants are usually high.

Thus, a balanced use of NRE sources, prioritizing cleaner fuels like natural gas over polluting ones, is required while also expanding RE penetration.

Comparative Analysis

A summary of the technical, environmental, and economic characteristics of RE and NRE technologies is presented in Table 1 based on the discussion so far.

Table 1. Comparative analysis of RE and NRE sources

Parameter	**Renewable Energy**	**Non-Renewable Energy**
Stability	Intermittent output; Requires forecasting and reserves	Stable and dispatchable output
Capital Costs	High capital costs; Low O&M costs	High capital costs offset by economies of scale
Operating Costs	Low to zero fuel costs; Higher integration costs	Reasonable levelized costs but uncertain fuel prices
Land Use	Requires large land areas	Compact siting with smaller footprint

Grid Services	Do not naturally support grid; Requires inverters	Provide inertia, voltage control and other ancillary services
Environmental Impact	Zero emissions during operation	Major source of air and water pollution
Water Use	Negligible water requirements	High water needs for thermal power plant cooling
Capacity Factors	10-40% for solar/wind; 30-60% for hydro/biomass	Above 50% for coal, CCGT, nuclear plants

RE provides clean and sustainable power but suffers from intermittency issues requiring forecasting, storage, and reserve determination. NRE gives stable generation but poses environmental challenges and fuel availability/cost concerns over the long term.

Each category offers complementary strengths for power grid operation. An optimal mix of RE and NRE sources, supported by energy storage technologies, flexible transmission, and smart grid management practices can help realize the benefits of both categories for affordable and reliable supply of electricity with minimal environmental footprint.

Future Pathways for RE-NRE Synergy

Some of the promising pathways to synergistically leverage the strengths of both RE and NRE sources within future power systems are discussed below [14]:

- Hybrid power plants combining RE, storage, and synchronous generators at the same site to provide firm and dispatchable power.
- Integrated resource planning models optimizing RE, NRE, and storage infrastructure at a regional scale over short and long-term horizons.
- Retrofitting existing NRE plants like coal with battery storage for fast ramping and load following capabilities.
- Using NRE plants to provide grid stabilizing services and peak power while meeting base loads with RE.
- Dynamic scheduling and coordination of RE and NRE plants along with pumped hydro storage and flexible transmission.
- Implementing smart grid technologies like advanced forecasting, communications, control, and cybersecurity to reliably manage high RE scenarios.

- Expanding small modular nuclear reactors which offer stable baseload power with modular construction benefits.
- Developing new energy carriers like hydrogen produced via RE for use in fuel cells, gas turbines, vehicles, and industrial applications.
- Implementing real-time, multi-objective ELD models for optimal scheduling of available generation.
- Evolving electricity markets, pricing mechanisms, and incentive structures to efficiently manage the RE-NRE mix.

Such innovative approaches can pave the way for tomorrow's low-carbon, reliable, and affordable power systems.

Conclusion

This paper presented a comparative review of the integration of renewable and non-renewable generation sources in the economic load dispatch framework which is essential for cost-optimal operation of power systems. RE introduces variability and uncertainty factors necessitating enhanced forecasting, storage use, grid stability considerations, and environmental dispatch. On the other hand, NRE provides stable and flexible generation but poses long-term availability and sustainability challenges. An optimal combination of RE and NRE resources, complemented by advances in flexible transmission, energy storage, forecasting, and smart grid technologies can help balance the synergies of the two categories. Hybrid plants, dynamic scheduling, small modular nuclear reactors, and integrated resource planning are some of the promising pathways for the future grid. Real-time multi-objective ELD implementations also help utilize the available RE and NRE sources in the most efficient manner. Through such synthesis, modern power systems can transition toward a more resilient, economical and sustainable electricity future.

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