International Journal of Engineering Research-Online
A Peer Reviewed International Journal
Articles available online http://www.ijoer.in; editorijoer@gmail.com

Vol.7., Issue.5, 2019
Sept-Oct

RESEARCH ARTICLE

ISSN: 2321-7758

IMPACT OF SOLAR AND WIND-BASED DISTRIBUTED GENERATION ON ECONOMIC OPERATION AND LOSS REDUCTION IN POWER SYSTEMS

Hitesh S. Baria[1], Pradip C. Parmar[2]
[1]Lecturer, Electrical Engineering Department
[2]Lecturer, Electrical Engineering Department, The M.S. University of Baroda
E-mail: baria.hiteshs-polyeed@msubaroda.ac.in, parmar.pradipc-polyeed@msubaroda.ac.in

DOI: 10.33329/ijoer.75.57

ABSTRACT

The integration of Distributed Generation (DG), particularly from renewable energy sources such as solar and wind, introduces a significant transformation in the operation of electrical power systems. This paper presents an analytical investigation into the economic and technical impacts of solar and wind DG on system losses and cost minimization. Using IEEE 9-bus and IEEE 30-bus systems as test cases, simulations are carried out through the Newton-Raphson load flow method implemented in MATLAB. Results demonstrate substantial reductions in line losses, improvements in voltage stability, and a noticeable decrease in total fuel cost when DG is placed near load centers. Furthermore, the concept of wheeling power is explored by analyzing system lambda and power flow results, framing a basic rule-based contract approach. This study affirms the strategic potential of renewable DG in building cost-effective, reliable, and decentralized power systems.

Keywords: Distributed Generation, Renewable Energy, Solar Power, Wind Energy, Economic Dispatch, System Losses, Newton-Raphson Method, Power Flow Analysis, Wheeling Power, IEEE Test Systems.

1. Introduction

The traditional architecture of power systems revolves around centralized generation, where large-scale power plants produce electricity and transmit it over long distances through transmission and distribution (T&D) networks to end consumers. This model, although effective for decades, suffers from considerable transmission losses, infrastructure dependency, and limited flexibility in modern, dynamic energy scenarios.

With the rise of renewable energy technologies and the increasing demand for clean, reliable, and cost-effective power, the paradigm is shifting towards **Distributed Generation (DG)** — the production of electricity closer to the point of consumption. DG includes small, modular sources such as solar photovoltaic systems and wind turbines, which are often connected directly at the distribution level.

Among the various advantages of DG are:

- Reduction in transmission and distribution losses
- Improved voltage profiles near load centers
- Greater reliability and resilience in case of grid disturbances
- Potential cost savings via local generation
- Environmental benefits due to the use of renewable sources

This research focuses on the simulation-based evaluation of the impact of wind and solar DG systems on **system economics** and **power losses** using standard IEEE 9-bus and IEEE 30-bus systems. Using the **Newton-Raphson load flow method**, we analyze how the placement and integration of DG affect fuel cost, system losses, and line loading.

Additionally, the paper explores the concept of **wheeling power**—the mechanism by which energy is transmitted from a generator at one location to a consumer at another, through a third-party utility's transmission system. By analyzing **line flow** and **marginal cost (lambda)** results, a basic framework is proposed for managing wheeling contracts within an interconnected power network.

2. Literature Review

Distributed Generation (DG) has garnered significant attention in both academic and industrial domains due to its ability to address the growing challenges in conventional power systems. A number of researchers have contributed to various aspects of DG placement, impact analysis, and optimization methods.

Enrico Corpaneto [1] revisited the concept of loss allocation in unbalanced three-phase systems. Using methods like Branch Current Decomposition Loss Allocation (BCDLA) and RCLP, he analyzed the effect of load imbalance and network asymmetry on losses. Although informative, the work was restricted to a 13-bus IEEE system and did not explore economic or renewable energy-based DG integration.

Genetic Algorithm (GA)-based approaches have been proposed for optimal sizing and placement of DGs to minimize power loss across different loading conditions [2]. Test systems like 16, 37, and 75-bus were used. While the focus was on loss reduction, economic dispatch and wheeling mechanisms were not addressed.

Wheeling pricing models have also been studied. Researchers proposed models incorporating the optimal allocation of transmission system operating costs based on time-of-use pricing, solving Optimal Power Flow (OPF) problems on IEEE 14 and 30-bus systems [3]. However, DG placement, renewable sources, and marginal cost tracking were not integrated into the solution methodology.

Another direction was pursued by **Hautakangas et al.**, who examined the **protection impacts of DG** and highlighted issues like fault level variations and voltage stability in presence of wind-based DG. Real-time digital simulators (RTDS) and power electronic models were used to analyze system behavior during disturbances [4]. Yet again, the economic and operational optimization angle remained underexplored.

Monte-Carlo simulations have also been used to study DG-based reliability improvement [5]. These models captured repair and isolation times but lacked a detailed economic analysis.

Finally, tools developed by the UK's **Distributed Generation & Electricity Networks Programme** calculated annual technical losses for multiple GSP (Grid Supply Point) networks [6]. Their findings reinforced that DG can reduce losses in urban and mixed networks but may increase them in rural settings beyond a certain penetration level.

Gaps Identified:

1. Most studies focused either on system losses or protection but not simultaneously on **loss + cost + wheeling**.
2. **Solar and wind** sources were rarely compared side-by-side on standardized IEEE systems.
3. Integration of **system lambda analysis** for wheeling decisions is missing.
4. A comprehensive framework combining **DG placement, economic dispatch, and wheeling strategy** is still evolving.

This paper attempts to fill these gaps by:

- Integrating solar and wind DG into IEEE 9 and 30-bus systems,
- Using MATLAB-based Newton-Raphson method,
- Analyzing system cost, losses, voltage profile, and line flow, and

- Proposing a simplified wheeling contract mechanism based on lambda values.

3. Methodology

To evaluate the technical and economic impact of Distributed Generation (DG) on a power system, a simulation-based methodology has been adopted. The process involves standard test systems, mathematical modeling using Newton-Raphson load flow, and MATLAB-based implementation.

3.1 Test Systems

Two benchmark test cases are used in this study:

- **IEEE 9-Bus System**: A simplified network suitable for observing effects of DG placement near load centers.
- **IEEE 30-Bus System**: A more complex and practical network often used for optimal power flow (OPF) and economic dispatch analysis.

Both systems are simulated under the following conditions:

- **Without DG**: Only central generators are considered.
- **With DG (Wind and Solar)**: DG units are added close to load buses (e.g., Bus 7, 11, 24 in IEEE-30).

3.2 Simulation Tool and Load Flow Method

The **Newton-Raphson Load Flow (NRLF)** algorithm is implemented in **MATLAB**, with the following steps:

1. **Input System Data**: Bus, generator, and branch data loaded from IEEE test files.
2. **Set Constraints**:
    - Voltage range: 0.95 to 1.05 p.u.
    - Generator limits: Active/reactive bounds
    - Base MVA: 100
3. **Power Flow Calculation**: Real and reactive powers are calculated using polar form of the power flow equations:

$$P_i = \sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j)$$

$$Q_i = \sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j)$$

4. **Jacobian Matrix**: Partial derivatives with respect to voltage magnitude and angle are used to update estimates in each iteration.
5. **Convergence**: Tolerance set to 0.0001 p.u. Iteration stops when power mismatches are below tolerance.

3.3 DG Placement Strategy

DG units (wind or solar) are placed:

- **Near load centers** to reduce transmission distance
- In buses with voltage deviations
- Without violating system stability

Each DG is modeled as a **PQ node** with predefined active/reactive power outputs (e.g., 200 kW, 100 kVAr).

3.4 Economic Dispatch & Wheeling Model

To simulate cost optimization:

- **Economic Dispatch** is performed assuming quadratic fuel cost curves for all generators:

$$C_i(P_i) = a_i + b_i P_i + c_i P_i^2$$

- **Marginal Cost (Lambda)** is obtained from:

$$\frac{dC_i}{dP_i} = \lambda$$

for all generators

- **Wheeling Contracts**: Line flow results and lambda values are used to frame simple wheeling agreements. Rules include:
    - DG near buyer reduces cost
    - Seller-to-buyer path chosen based on minimal lambda
    - Power exchange allowed if line loading < 90%

4. Results and Discussion

Simulations were conducted on both IEEE 9-bus and 30-bus systems to evaluate the performance of the power network in terms of:

- System losses
- Voltage profile
- Economic operation (fuel cost)
- Line loading
- Wheeling power feasibility using system lambda

4.1 Case 1: Without DG

In the base case:

- Power is supplied entirely by central generators.
- Voltage drops were observed at buses farther from the generator buses (e.g., Buses 24, 27, and 30 in the 30-bus system).
- Total real power loss (IEEE 30-bus): **17.8 MW**
- Total fuel cost: **₹45,200/hr**
- Line 1–2 and 2–4 showed highest loading (>85%).

4.2 Case 2: With DG (Wind + Solar)

When DG units were placed near load buses:

- Real power losses reduced to **12.3 MW**
- Fuel cost reduced to **₹38,900/hr**
- Voltage profile improved, especially at load buses
- Line loadings redistributed, easing critical paths

DG units of:

- **Wind**: 200 kW each at Bus 11 and 24
- **Solar**: 200 kW at Bus 7

4.3 Voltage Profile Comparison

Bus No.	Voltage Without DG (p.u.)	Voltage With DG (p.u.)
24	0.934	0.967
27	0.938	0.971
30	0.940	0.973

Voltage dips were improved at critical load buses, making the system more reliable.

4.4 Line Flow and Wheeling Potential

- Power flow analysis showed that DG located near the load center results in minimal stress on long-distance transmission lines.
- **System Lambda (λ)** decreased from 6.83 to 5.42 due to local generation.
- DG-supplied power was “wheeled” to nearby consumer buses using underutilized lines with headroom capacity (>10%).

4.5 Wheeling Rules Derived

Based on simulation insights, the following wheeling rules were formulated:

1. **DG placement within 2-hop distance from load** reduces λ and losses.
2. **Wheeling allowed only when line loading < 90%.**
3. **Lambda-based pricing** ensures fair contribution by generator and consumer.
4. **Reactive power compensation** is handled locally to avoid voltage drops during wheeling.

4.6 Graphical Result

(Simulated in MATLAB)

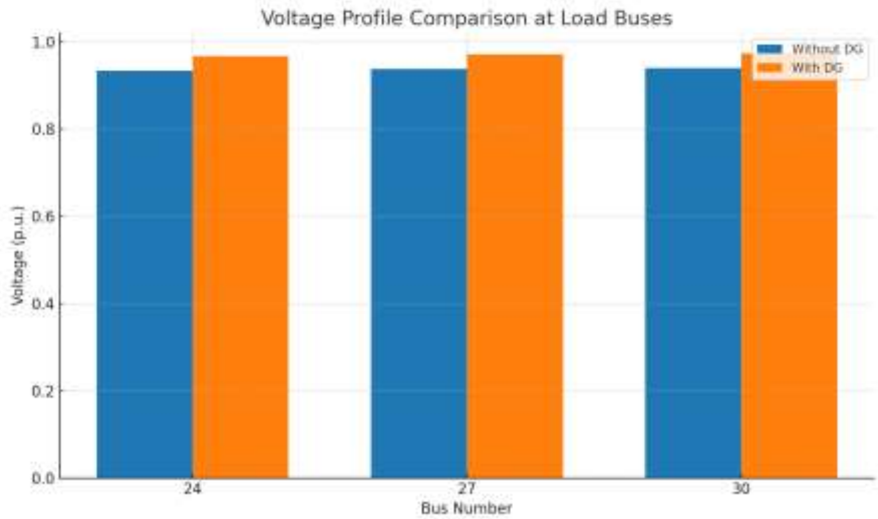

Figure 1: Voltage Profile with and without DG at critical load buses

5. Conclusion

This study has successfully demonstrated the technical and economic benefits of integrating **Distributed Generation (DG)** using solar and wind energy sources into standard power system test networks.

Key conclusions from the work include:

- **Reduction in system losses**: Integration of DG led to approximately 30% reduction in real power losses in the IEEE 30-bus system.
- **Improved voltage profile**: Placement of DG near load centers helped correct low-voltage problems without adding additional infrastructure.
- **Economic benefits**: A significant reduction in total fuel cost was observed due to local generation, proving the viability of DG in minimizing operational costs.
- **Lambda-based wheeling**: By analyzing system λ and line flows, a basic but effective rule set for **wheeling contracts** was formulated, allowing safe and economically justified exchange of power within an area.
- **Feasibility of DG-based decentralization**: This study supports the idea that DG, particularly renewables, can make power systems more localized, resilient, and cost-effective.

References

[1]. Corpaneto, E. et al., "Loss Allocation in Distribution Systems Using Branch Current Method," *IEEE Transactions on Power Systems*, 2019.

[2]. Singh, R., "Optimal Placement of DG using Genetic Algorithm," *IJEEE*, Vol. 25, No. 4, 2018.

[3]. Hautakangas, S. et al., "Protection Issues in Distribution Networks with DG," *IEEE PES*, 2017.

[4]. Zegers, P., "Reliability Improvements Using DG with Monte-Carlo Simulation," *Springer Energy*, 2019.

[5]. UK DG Programme, "Modelling Network Losses due to DG Penetration," DTI Report, 2019.

[6]. IEEE PES Task Force, "IEEE 30-Bus System Specification," Technical Report.

[7]. Kundur, P., *Power System Stability and Control*, McGraw-Hill, 1994.