ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 12, Issue 11, November 2025

Investigation of Power Flow Variations in Sources Connected to Distributed Generation

J.N.Tolipov

Institute of Energy Problems of the Academy of Sciences of the Republic of Uzbekistan

ABSTRACT: This paper provides a comprehensive analysis of the variations in power flows in electrical networks connected to distributed generation sources and their impact on network stability. Load dynamics, time-dependent changes in generation capacity, network topology reconfiguration, and high line R/X ratios are considered the main factors influencing power flow formation. Mathematical models representing active and reactive power balance are applied to evaluate voltage stability, loss reduction, and processes related to changes in power flow direction. The integration of distributed generation is found to reduce voltage drops, improve network efficiency, and decrease dependence on central power sources. At the same time, challenges such as reverse power flow, relay-protection system adjustments, and power quality issues are identified. Overall, the proper integration of distributed generation into the network plays a crucial role in enhancing the reliability and efficiency of electricity supply.

KEYWORDS: distributed generation, power flow, electric grid, voltage stability, reactive power balance, reverse power flow, load dynamics, energy losses, solar power station.

I. INTRODUCTION

Studying the variations of power flows in electrical networks connected with distributed generation sources is an important process for improving network performance and maintaining power quality. Power flows can change for various reasons, including load fluctuations, inherent irregularities in the operation of generation sources, and interactions among network elements. Moreover, these changes in power flows can affect network stability, cause energy losses, and lead to technical malfunctions. Therefore, analyzing and monitoring these power flows is essential for effective management and optimization of power distribution. In this process, mathematical models and real-time monitoring serve as the primary tools.

In distribution networks, lines have a high ratio of active and reactive impedance, and active power flow significantly affects voltage drops and losses. When distributed generation is connected to such a network, even a small amount of power can noticeably change the voltage. For example, in a long section with a high load and no local generation, a voltage drop is observed at the end of the line; adding distributed generation there reduces this drop. However, the presence of automatic voltage regulators, compensators, and other equipment in the network is also a factor that determines the impact of distributed generation, as connecting distributed generation alters their operation. For instance, if line current decreases due to local generation, the automatic transformer regulator will increase the voltage less than usual, which may result in insufficient voltage for distant consumers. Moreover, connecting distributed generation forces changes in the settings of protection relays and automatic circuit breakers. In general, the impact of distributed generation on the network depends on its capacity, location, type, and network characteristics, as noted in various studies. Therefore, these factors must be considered when integrating distributed generation into the network.

II. OBJECT

When distributed generation sources operate in the network, the time-dependent variations of power flows occur according to different conditions. The main scenarios can be conditionally classified into the following types:

Load variation: Temporary changes in network load directly affect power flows. For example, in the evening hours, when consumer demand increases, the output of local generation may remain relatively low (in the case of solar photovoltaic plants, production stops at sunset). In this situation, the main power of the network flows from the high-voltage side (substation) to the consumers as usual. On the other hand, during the daytime, when the load

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 12, Issue 11, November 2025

is low and generation (for example, a solar photovoltaic plant on a sunny day) is high, the demand for power flow through the network decreases.
In cases where a decrease in load is compensated by excess local generation, the surplus power may flow back to higher voltage levels, causing changes in the direction of power flow within network sections. Therefore, during periods of light load, power flow may reverse direction, while during peak load periods, it may return to a unidirectional flow. When analyzing the network, it is necessary to separately consider the most severe scenario (maximum load, minimum generation) and the lightest scenario (minimum load, maximum generation), as these two extreme cases result in the greatest differences in voltage levels and current distribution.
The following mathematical models are used to perform these analyses. They take into account multiple variables simultaneously, including the time of day and night, generation capacity, load dynamics, line parameters, transformer status, reactive power compensation, and others.

$$P_i(V,\delta) = V_i \sum_{j=1}^{N_B} V_j\left[G_{ij}\cos\left(\delta_i - \delta_j\right)\right] + B_{ij}\sin\left(\delta_i - \delta_j\right) - P_{di} + P_{gi} = 0$$

In this case V_i - i- voltage amplitude at the bus, δ_i - phase, G_{ij}, $B_{ij,}$ - elements of the admittance matrix, P_{di}- load power, P_{gi} - generation power.
Secondly, the reactive power balance is determined by the following equation:

$$Q_i(V,\delta) = V_i \sum_{j=1}^{N_B} V_j\left[G_{ij}\sin\left(\delta_i - \delta_j\right)\right] + B_{ij}\cos\left(\delta_i - \delta_j\right) - Q_{di} + Q_{gi} = 0$$

This equation models the distribution of reactive power, providing the ability to maintain voltage stability and properly manage compensation devices.
Topology Change (Network Reconfiguration): Changes in the network topology can occur in a power system due to faults or for operational control purposes—for example, when a line or transformer is temporarily disconnected and the network is supplied through an alternative route, or in a looped network when sectionalizing switches are opened or closed to reconfigure the system. When the network topology changes, the paths of power flows are altered, and the loads on certain network sections are redistributed. For instance, if a section is disconnected due to a fault, the loads in that section may be locally supplied by distributed generation sources in neighboring sections. Alternatively, when reconnecting the network to balance the loads, part of the power flow may be redirected to another line. As a result, the load decreases on some lines, increases on others, and overall losses change. Thus, reconfiguring the network allows for managing power flows and potentially reducing losses. Topology change scenarios also include reconnecting the network according to load requirements and post-fault restoration processes.
In distributed generation sources such as solar photovoltaic (PV) plants or wind turbines, the variability of power is often mathematically modeled using a time-dependent function for power output (P). Based on this, formulas are applied to calculate the power flow at the bus.
The active power calculation equation through the time-dependent variation of generation is defined as:

$$P_{gi}(t) = P_{MAX} \cdot f(t)$$

In this case P_{gi} (t) – i- generator's power over time, kW, P_{max} – generator's maximum power, kW, f(t) – time-dependent normalized output function, $0 \le f(t) \le 1$.

III. KEY FINDINGS AND ENERGY CONSERVATION OPPORTUNITIES

Power flow direction: In a centralized electricity supply system, electric power is usually transmitted in one direction—from the high-voltage level (transmission network) to the low-voltage level (distribution network) and then to consumers. Distributed generation, however, is significant because it can make power flows bidirectional—power can now move not only from the substation to the load but also from the load back toward the substation. As mentioned earlier, if distributed generation produces more power than the local load consumes, the excess energy flows backward to the higher-voltage network through neighboring lines and substation transformers. This phenomenon is referred to as reverse power flow.
For example, during sunny periods, photovoltaic (PV) sources in a small village network may generate more power than the local consumption, and this excess energy can flow back to the substation in the district center, from where it is directed to other consumers in the area. Changes in the direction of power flow also affect the network's relay protection system—traditional protection devices operate based on the direction of current, and

power arriving from both directions may cause them to operate incorrectly. For this reason, in networks with widespread distributed generation, protection and automatic control systems need to be reviewed and adjusted.

IV. METHODOLOGY

The daily variation of power flow is illustrated in Figure 1 through the graphs of the network's total load, total solar generation, and the power transmitted through the central substation. From this graph, it is clearly seen how the power balance and the direction of flow in the network change at different times of the day.

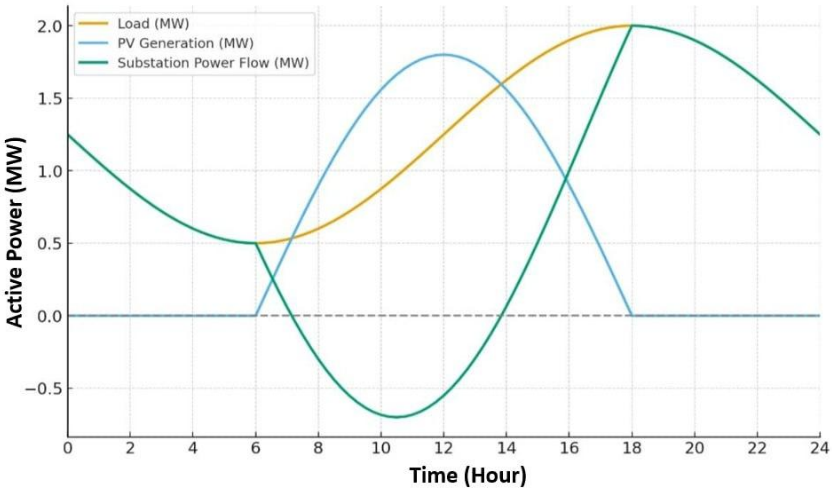

Figure 1. Graphs of the network load, solar generation, and power transmitted through the central substation.

As a result of integrating distributed generation into the network, power flow patterns acquire a new quality. The positive aspects include: local generation supports voltage levels, reduces voltage drops for distant consumers, decreases losses, and reduces the need to supply power to long network sections. For example, after adding distributed generation, load drops in the lines decreased by 16%, and the network's dependence on the central source was reduced – meaning that less power is drawn from the central network due to the contribution of local sources. This, in turn, increases the overall efficiency of the network, lowers peak loads, and improves supply reliability.

V. CONCLUSION

According to the research results, the integration of distributed generation sources into electrical networks significantly affects power flow variations, impacting network stability, voltage conditions, and energy losses. Load dynamics, variability in generation output, and changes in network topology are the primary factors shaping both the direction and magnitude of power flows. Local generation reduces voltage drops, alleviates line loads, and increases overall energy efficiency. At the same time, reverse power flows, the need to readjust relay protection systems, and certain power quality issues may arise. Overall, the proper integration of distributed generation into the network plays a crucial role in ensuring a stable, efficient, and reliable electricity supply.

REFERENCES

1. Reza Dashti, Mojtaba Rouhandeh, "Power distribution system planning framework (A comprehensive review)", Energy Strategy Reviews, Volume 50, 2023, 101256, ISSN 2211-467X, https://doi.org/10.1016/j.esr.2023.101256.
2. Glover, J. D., Sarma, M. S., & Overbye, T. J. Power System Analysis and Design. Cengage Learning, 2017.
3. Ackermann, T. Distributed Generation: A Definition. Electric Power Systems Research, 2001.
4. Lopes, J. A. P., Hatziargyriou, N., Mutale, J., Djapic, P., & Jenkins, N. "Integrating Distributed Generation into Electric Power Systems: A Review of Drivers, Challenges and Opportunities." Electric Power Systems Research, 2007.
5. Short, T. A. Electric Power Distribution Handbook. CRC Press, 2014.
6. Begovic, M., et al. "Impact of Renewable Distributed Generation on Power System Dynamics." IEEE Transactions on Power Systems, 2011.
7. T. Saravanan and G. Saritha and V. Srinivasan, Optimal Power Flow Using Particle Swarm Optimization, Middle-East Journal of Scientific Research 20 (11): 1554-1560, 2014.