

THE IMPACT OF THE REVERSE CIRCULATION EFFECT IN ELECTRICAL NETWORKS

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Abstract. The traditional electricity grid was designed to ensure a one-way flow of energy, from generation (production) to consumption, through transmission and distribution networks. However, as global energy demand evolves, traditional systems are changing their dynamics to integrate more and more renewable energy sources.

Key words: power flow, renewable energy sources, energy transition

1. INTRODUCTION

The growing focus on reducing environmental pollution from electricity generation, along with the need to use energy more efficiently, has encouraged a wider implementation of renewable energy sources. These include both natural resources such as wind and solar power, as well as residual heat from thermal processes, all aimed at minimizing environmental impact.

A rational balance is needed between expanding renewable energy sources - whose output cannot be fully controlled - maintaining the security of the energy system, and limiting the land allocated for renewable installations so as to avoid reducing agricultural areas essential for food production (the food-energy conflict).

Generating electricity is a process that produces considerable polluting emissions, more around of power plants. Expanding the use of renewable energy sources, which have very low operational emissions, offers an effective way to reduce pollution. Primary energy resources such as solar, wind, hydro, or geothermal energy do not generate pollutants during their conversion into electricity, are practically inexhaustible, and - when combined with energy storage systems - can also be treated as controllable sources.[1]

Integrating renewable energy sources into the power system significantly influences its performance, particularly when done on a large scale, and introduces risks due to the unpredictable nature of their output. Sudden drops or interruptions in production can create challenges in maintaining system stability. The use of energy storage systems enables better control of these sources by smoothing out fluctuations

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caused by weather-dependent generation. When managed intelligently, renewable energy can offer substantial benefits to users who operate such systems [3], [4].

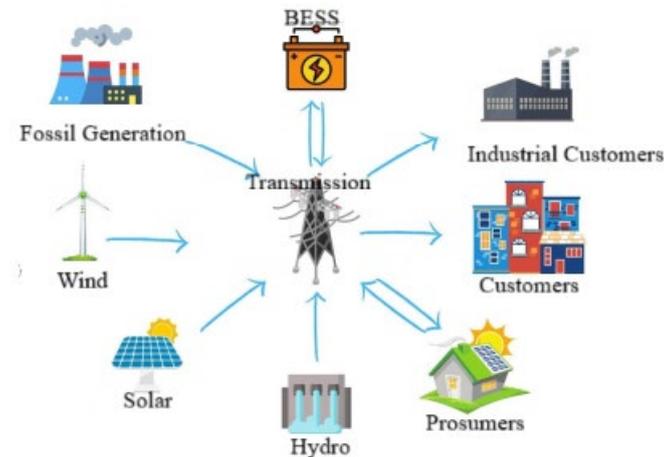


Fig.1 The structure of future energy transmission

The goal of lowering energy costs by reducing consumption from the public grid has encouraged many consumers to install renewable sources (typically solar) along with storage solutions. Effective active power regulation and source flexibility are crucial for ensuring the successful commercial integration of these systems.

The variability of primary energy sources, taking into account the uncontrollable aspect of the energy supply of weather-dependent sources as well as the variability of the usage curve, determines that the existence of electrical energy storage systems is of particular interest for controlling the functioning of the energy system.[5]

2. THE REVERSE POWER FLOW

The process of integration and interconnection of DG into existing power systems is complex, involving technical challenges regarding power quality and protection, functional challenges regarding load balancing, regulatory challenges regarding equitable access, and political challenges encouraging action to achieve societal objectives. However, the benefits of DG, such as the ability to harness RES, many of which are naturally dispersed, make it essential for their widespread adoption in the relatively near future. [1],[3], [12]

Especially during summer midday hours, when solar irradiance peaks and the demand from consumers connected to low- and medium-voltage networks is low, PV installations can generate a reverse power flow, as the consumption in these networks may fall below the power produced by the photovoltaic systems. The use of energy storage solutions by active users can help counteract and reduce this effect.

Because distribution networks are originally designed for one-way power flow, the voltage gradually decreases with distance from the generator toward the transformer. These voltage drops are predictable and are factored into the network's

design to ensure that voltage stays within acceptable limits under normal operating conditions. However, when a distributed generation (DG) unit is added, the direction of current flow changes—or can even reverse—causing the voltage to rise in ways that are harder to anticipate. Meeting voltage limit requirements therefore imposes constraints on the amount of DG capacity that can be connected to the grid, especially at low-voltage levels [4], [11].

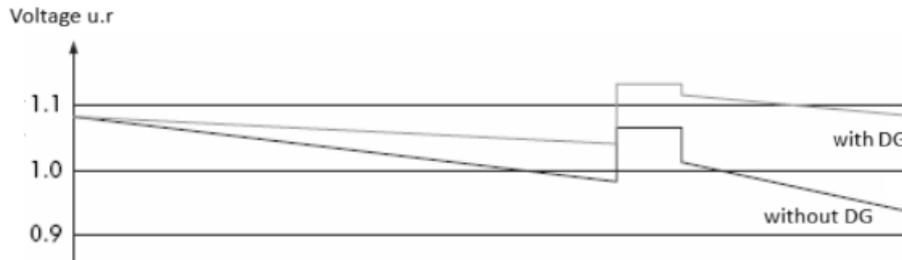


Fig.2 Voltage increase due to reversal of power flow due to DG

In the same time with the increase the number of sources connected via frequency converters, it becomes necessary to develop artificial inertia schemes that provide the necessary support for limiting the rate of change of and improving the dynamic stability conditions of the system. With the increase in the share of energy produced from renewable sources, their effects on the quality of electricity must be taken into account: the occurrence of voltage harmonics, electrical current imbalances, the occurrence of voltage fluctuations, the possibility of bidirectional power circulation in the user's power supply network. During the hours of maximum production of renewable sources, it is possible to result in changes in power flows in the network, as well as changes in the values and direction of electrical currents in the event of a fault.

Generally these sources are connected to public electricity through inverters that allow control over two output parameters: active power and reactive power[6],[7]. When PV sources generate active power, they can alter the voltage profile within the grid. Consuming reactive power can lower the voltage with minimal effect on active power output, making this the preferred approach. Reducing active power can help mitigate overvoltages in the network, but it also decreases the total energy produced by the system and is typically applied only when voltages are very high and reactive power control alone cannot resolve the issue.

The reverse circulation of power in the circuit with renewable sources operating in capacitive mode can lead to an increase in the magnetizing electric current of the transformer and to a change in its characteristics [2], [3].

Additionally, changes in the transformer's magnetization characteristics can generate harmonics in the electric current, leading to increased losses in the power supply network. Limiting the energy fed into the public grid for operational reasons is generally unacceptable to investors, who aim to maximize the energy delivered. Equipping local renewable sources with energy storage systems allows excess energy to be absorbed and helps reduce reverse power flow conditions.

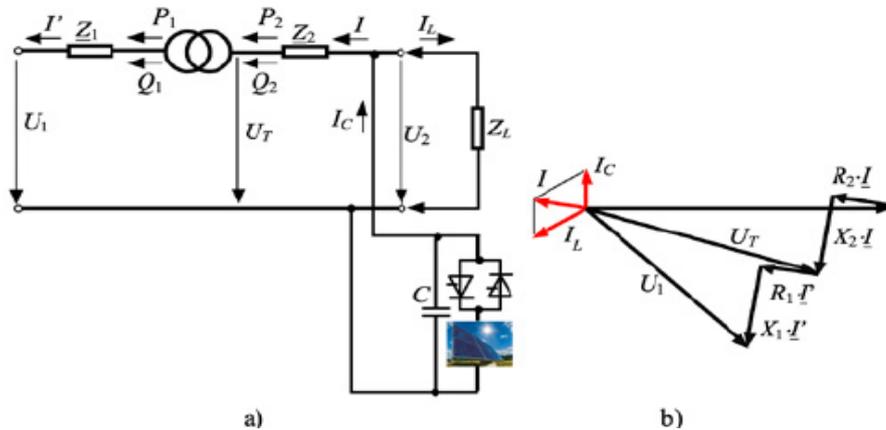


Fig.3. Reverse power flow in circuits with renewable sources
 a) schematic diagram; b) phasor diagram

3. THE EFFECT OF REVERSE POWER FLOW IN MODERN ELECTRICAL NETWORKS

Reverse circulation appears when the electricity produced locally—usually by distributed renewable sources—surpasses the consumption of nearby users. In this situation, the excess energy flows backward toward the transmission grid or other points in the distribution network. In other words, the power starts moving “upstream,” contrary to the grid’s original design, which anticipated electricity flowing in only one direction, from centralized power plants to consumers. [5],[8]

The impact of the reverse circulation effect is particularly important in modern electrical networks, where these phenomena can lead to:

- power quality issues, they can generate fluctuations in voltage and frequency, affecting the stable operation of the electrical system.
- increased risk to equipment and user safety, such situations may create operating conditions that were not considered in the original network design.
- challenges in load balancing, managing rapidly changing energy flows becomes more difficult, especially when renewable generation cannot be accurately predicted.
- interference with network and protection system operation, when energy begins to flow opposite to the usual direction, the protection schemes may no longer function as intended, leading to possible malfunctions.
- overloading of network components, reverse power flows may overtake the designed capacity of transmission lines and transformers [9], [10].

3.1. Technical effects

-Voltage and frequency instability:

- feeding surplus energy back into the main grid can disrupt the system’s operating conditions, leading to:
- rapid voltage rises at nearby nodes.

- frequency variations that may interfere with the functioning of sensitive devices.
 - Harmonics and power quality concerns:
 - distributed generation units, particularly PV inverters, can inject harmonic distortions into the grid, negatively influencing.
 - the overall stability of the power system, and the proper functioning of devices connected to the network.[13]
 - Issues with protection relays:
 - traditional protection relays are configured to identify faults assuming power flows only in one direction. When the flow reverses, they may incorrectly interpret it as a fault, potentially triggering unwarranted disconnections.
 - Overloading of equipment.
- Transformers and power lines are built for power to move in a single direction, when the flow reverses, it can lead to:
- increased energy losses caused by the Joule effect [1], [8], [12], [14]
 - excessive heating, faster deterioration of insulation, and a shorter operational lifetime of the equipment.

3.2. Economic effects

Billing challenges

- without bidirectional metering, accurately accounting for energy exchanged with the grid becomes difficult, potentially causing revenue losses for network operators.
 - Decreased energy efficiency
- overloaded transmission lines and transformers lead to higher energy losses.
- excessively stressed equipment must be replaced more often, which raises maintenance expenses.
 - Need for additional investments
- upgrading the grid to accommodate two-way power flows requires significant financial resources.

3.3. Operational effects

- Higher risk of outages:
- uncontrolled bidirectional flows can lead to failures within the local network or at consumer installations. [14]
 - Increased operational complexity, managing power flows in both directions demands:
- continuous real-time monitoring.
- the use of advanced optimization algorithms.

4. CONCLUSIONS

The continued growth of the number of energy sources connected to an operator's network—and the corresponding rise in locally generated power—can

introduce new power flow patterns that must be identified and managed under various operating conditions.

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