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# Impact of RDG Location on IDMT Overcurrent Relay Operation and Coordination in MV Distribution System

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***Abstract***

*In recent years there has been an intensive effort to increase the participation of renewable sources of electricity in the fuel and energy balance of many countries. In particular, this relates to the power of wind farms attached to the power system at both the distribution network. However, in the presence of Renewable Dispersed Generation, (RDG) some problems in coordination of protection devices will occur, due to changes in fault current levels at different points. By installing RDG in power distribution networks, the fault current levels are changed and may lead to some miscoordination in IDMT Directional Over-Current Relay (DOCR). In this paper, a novel approach is presented to study the impact of RDG location ($d_{RDG}$) on IDMT characteristic curve of relay, fault current ($I_F$), operation time (T) for DOCR, and coordination time interval (CTI) between backup and primary relays and short circuit level index (ISC) in the presence there phase fault on medium voltage (MV) distribution network. This new approach has been implemented on the Algerian 10 kV distribution power system in Constantine.*

***Keywords**: renewable dispersed generation (RDG), directional overcurrent relay, fault current, operation time, coordination time, short circuit level index.*



## 1. Introduction

Due increased consumption demand and high cost of natural gas and oil, using of Renewable Dispersed Generation (RDG) resources as alternative to feed electrical loads has been increased in recent years. RDG is defined as energy sources (ranging in size from few kilowatts to megawatts) connected directly to the distribution network of a power system. Using RDG is an interesting topic that has drawn attention of electrical engineers in recent years. The presence of these generation units in distribution systems, although has many advantages and benefits, has to be applied after performing detailed studies and investigations due to their complexities in operation, control and protection of network. One of the major effects of RDG is their effect on protection operation of distribution networks [1].

Therefore, interest in the integration of RDG into distribution systems has been rapidly increasing. RDG is loosely defined as small-scale electricity generation fueled by renewable energy sources, such as wind and solar, or by low-emission energy sources, such as fuel cells and micro-turbines. The RDG presence in power systems is one of attractive phenomena in power industry [2]. With the presence of RDG units in distribution systems, its function would generally be changed and it would variously be affected by these units. RDG, which is sometimes referred also as embedded generation, means primarily small size generation units connected to the distribution power system. Integration of a RDG into an existing distribution system has many impacts on the system, with the power system protection being one of the major issues [3].

For RDG location in the distribution power systems, various issues, such as reduction of system power loss in [4, 5], active power loss reduction and voltage profile improvement in [6], power loss minimization in distribution system reconfiguration in [7], maximization of DG capacity in [8], minimization of investment planning in [9], analyses stability and sensitivity in [10], minimization reactive power losses for different load models in [11], minimization voltage collapse in [12], amelioration power factor in [13], minimization energy cost in [14], minimization of system average interruption duration index (SAIDI) in [15], minimize cost and maximize total system benefit in [16], maximize total DRG active power capacity in [17], study of economical-

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technical impacts RDG on MV radial distribution system in [18], impact on multi-area automatic generation control for frequency control in [19], and maximisation of distribution network operators in a deregulated environment in [20].

In this paper study impact of RDG location for penetration level of RDG varied between 0.5, 1.0, and 1.5 MW installed at midline on fault current ($I_F$), short circuit level index (*ISC*) and performance of IDMT directional overcurrent protection: IDMT characteristic curve, operation time (*T*) and coordination time interval (*CTI*) between primary and backup overcurrent relays in the presence of three phase fault on reel power system in Algerian medium voltage (10 kV) distribution network installed in Direction of Constantine.

## 2. Impact of RDG on Power System

Based on the literature, there is no consistent definition of Distributed Generation (DG), but generally they are small-scale generation units located near or at loads. However, the definition can be diversified based on voltage level, unit connection, type of prime-mover, generation not being dispatched, and maximum power rating [21]. IEEE [22] defines DG as “the generation of electricity by facilities that are sufficiently smaller than central generating plants so as to allow interconnection at nearly any point in a power system”, IEEE compared the size of the RDG to that of a conventional generating plant. A more precise definition is provided by the International Council on Large Electric Systems (CIGRE) and The International Conference on Electricity Distribution (CIRED), which defines RDG based on size, location, and type. CIGRE defines distributed generation as “all generation units with a maximum capacity of 50 MW to 100 MW, that are usually connected to the distribution network and that are neither centrally planned nor dispatched”. CIRED defines DG to be “all generation units with a maximum capacity of 50 MW to 100 MW that are usually connected to the distribution network”.

The use of renewable energy sources (RES) or renewable dispersed generation (RDG) either as distributed generators in public AC networks or as isolated generating units supplying is one of the new trends in power-electronic technology. RDG equipped with electronic converters can be attractive for several reasons, such as environmental benefits, economic convenience, and social development. The main environmental benefit obtained by using renewable sources instead of traditional sources, is the reduction in carbon emission. Many countries have adopted policies to promote renewable sources in order to respect the limits on carbon emission imposed by international agreements.

Moreover, RDG can be economically convenient in comparison with traditional sources; if the economic incentives for grid connected renewable sources are taken into account or in other particular situations to supply stand alone loads. In some cases, it can be more convenient to supply an isolated load with renewable local source instead of extending the public grid to the load or to supply it with diesel electric generators [23]. In this case, in order to evaluate the economic benefits of renewable energy solution, it is necessary to take in account either the cost of the fuel or the cost of its transport to the load that can be located in remote and hardly reachable areas. In addition to the economic benefits, the use of distributed renewable generation units contributes to decentralize the electrical energy production, with a positive impact on the development of remote areas. The exploitation of local renewable sources supports local economies and lightens the energy supply dependency from fuels availability and prices fluctuations [24].

The integration in the electric grid of distributed power generation systems, located close to the loads, reduces the need to transfer energy over long distances through the electric grid. In this way several benefits are achieved, such as the reduction of bottle-neck points created by overcharged lines, the increase of global efficiency and the limitation of thermal stress on grid conductors. Renewable distributed generation units, if properly controlled and designed can improve the power flow management on the grid and reduce the probability of grid faults, so increasing the power quality of the energy supply. Large scale integration of RDG at either LV or MV is at the present the trend followed in power systems to cover the supply of some loads.

These generators are of considerable smaller size than the traditional generators [2]. Connection of RDG is intended to increase the reliability of power supply provided to the customers, using local sources, and if possible, reduce the losses of the transmission and distribution systems. The installation of RDG takes less time and payback period. Many countries are subsidizing the development of renewable energy projects through a portfolio obligation and green power certificates. This incentives investment in small generation plants. Some DG technologies have low pollution and good overall efficiencies like combined heat and power (CHP) and micro-turbines. Besides, renewable energy based DG like photovoltaic and wind turbines contribute to the reduction of greenhouse gases. Depending on the network configuration, the penetration level and the nature of the RDG technology, the power injection of RDG may increase the power losses in the distribution system.

## 3. Three Phase Fault Calculation in the Presence of RDG

To demonstrate the effect of a *RDG* unit on the fault current in a feeder, a generic feeder is given as a reference as shown in Figure 1. At distance $d_{RDG}$ a *RDG* unit is connected and at the end of the feeder, a three-phase fault (*F*) is simulated.

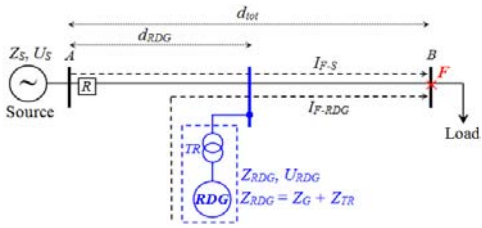


Figure 1. Fault Current Contribution in Presence RDG

Therefore, a distance parameter to indicate the location of the RDG, which is relative to the total feeder length, is defined as:

$$l = \frac{d_{RDG}}{d_{tot}} \tag{1}$$

Where, $d_{RDG}$ is the distance to the RDG unit, $d_{tot}$ is the total feeder length, and *l* is the relative RDG location. An electric equivalent of the feeder shown in Figure 1 is given in Figure 2. In this figure, $Z_L$ is the total line-impedance, $Z_{RDG}$ is the RDG impedance and $Z_S$ is the source impedance. The voltages of the main source and RDG unit are denoted as $U_S$ and $U_{RDG}$ respectively.

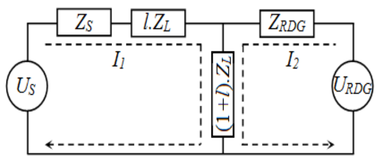


Figure 2. Network Equivalent Circuit

Defining the mesh currents $I_1$ and $I_2$ and applying the Kirchhoff's voltage law for $U_S$ and $U_{RDG}$, we get:

$$\begin{bmatrix} U_S \\ U_{RDG} \end{bmatrix} = \begin{bmatrix} Z_S + Z_L & (1-l).Z_L \\ (1-l).Z_L & Z_{RDG} + (1-l).Z_L \end{bmatrix} . \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} \tag{2}$$

Where, $I_1$ is the grid contribution of the $I_{F-S}$, $I_2$ is the RDG contribution of the $I_{F-RDG}$, $Z_S$ is the source impedance, $Z_L$ is the total line impedance, $U_S$ is voltage for source and $U_{RDG}$ is voltage for RDG. To determine expressions for $I_{F-S}$ and $I_{F-RDG}$, the Thevenin equivalent circuit of the above network is derived as shown in Figure 3.

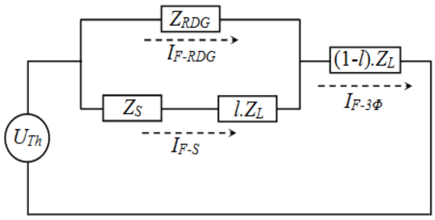


Figure 3. Thevenin Equivalent Circuit

From Figure 3, the Thevenin impedance is derived and given as:

$$Z_{Th} = \frac{(Z_S + l.Z_L).Z_{RDG}}{Z_S + l.Z_L + Z_{RDG}} + (1-l).Z_L \quad (3)$$

The total three-phase fault current can be calculated by:

$$I_{F-3\phi} = \frac{U_{Th}}{\sqrt{3}.Z_{Th}} \quad (4)$$

Substituting Equation (3) into Equation (4) yields:

$$I_{F-3\phi} = \frac{U_{Th}.(Z_S + l.Z_L + Z_{RDG})}{\sqrt{3}\left[A + B + C + l.Z_L(Z_L - Z_S) - l^2 Z_L^2\right]} \quad (5)$$

Where, the coefficients *A*, *B* and *C* are defined as:

$$Z_L Z_{RDG} = A \quad (6)$$

$$Z_S Z_{RDG} = B \quad (7)$$

$$Z_S Z_L = C \quad (8)$$

For the grid contribution holds:

$$I_{F-S} = \frac{Z_{RDG}}{Z_{RDG} + l.Z_L + Z_S} \times I_{F-3\phi} \quad (9)$$

Substituting Equation (5) into Equation (9), gives the RDG contribution of the short circuit current:

$$I_{F-S} = \frac{U_{Th}.Z_{RDG}}{\sqrt{3}\left[A + B + C + l.Z_L(Z_L - Z_S) - l^2 Z_L^2\right]} \quad (10)$$

The total short-circuits current, $I_{F-3ph}$, which is given by Equation (5) is a non-linear current. $I_{F-S}$ is also non-linear as given by Equation (9). In case of a weak grid, $Z_S$ can be as large as $Z_{RDG}$ and due to the contribution of the generator, the grid contribution to the fault current decreases. Short Circuit Level Index (ISC) is index is related to the protection and sensitivity issues since it evaluates the short circuit current or fault courant at each bus with and without RDG [25].

$$ISC = \frac{I_{F\ Without-RDG} - I_{F\ With-RDG}}{I_{F\ Without-RDG}} \quad (11)$$

## 4. Coordination of IDMT Directional Ouvercurrent Relay

Directional Over-Current Relays (DOCR) is widely used to protect power system elements such as power transformers, transmission and distribution lines, etc. When applied for protecting distribution feeders, they are usually associated with fuses and reclosers DOCR are coordinated to provide backup protection to a neighbour element, but maintaining the desired selectivity. A primary relay may have more than one backup relay and every pair of primary and backup relays should be coordinated.

The use of the same inverse curve and different time dial parameters to set the relays guarantees that once coordination for the maximum fault current is achieved, cases with lower fault current are also coordinated. The directional overcurrent relays employed in this paper are considered as numerical with standard IDMT characteristics that comply with the IEC 60255-3 standard, and have their tripping direction away from the bus [26].

$$T = TDS \times \frac{\alpha}{\left( I_M / I_P \right)^{\beta} + \gamma} \quad (12)$$

And,

$$I_M = \frac{I_F}{K_{CT}} \quad (13)$$

Where, $T$ is relay operating time (*sec*), $TDS$ is time dial setting (*sec*), $I_P$ is pickup current (*A*), $I_F$ is the fault current (*A*), $I_M$ is the fault current measured by the relay (*A*), and $K_{CT}$ is ration of current transformer. The constant $\alpha$, $\beta$, and $\gamma$ that depends of characteristic curve for IDMT overcurrent relay.

However, it can be shown that the proposed method can be easily applied to a system with combination of overcurrent relays with different characteristics as presented in Figure 4.

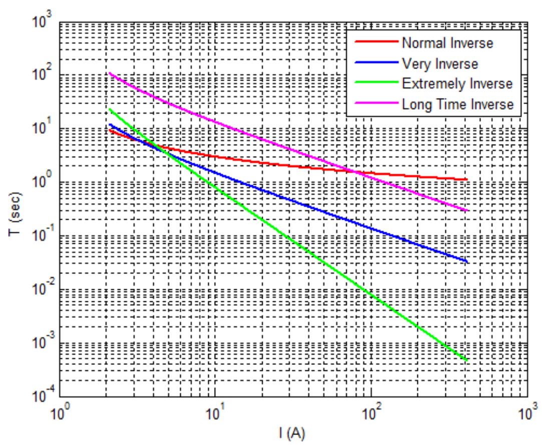


Figure 4. Time-current of IDMT Overccurent Relaying Characteristics

Table 1 below shows the constants values corresponding to each curve characteristic made standard IEC 60255-3 [27]:

Table 1. Different Type of Characteristics Curves

| *Type* | $\alpha$ | $\beta$ | $\gamma$ |
|---|---|---|---|
| Normal Inverse (NI) | 0.14 | 0.02 | 1.00 |
| Very Inverse (VI) | 13.5 | 1.00 | 1.00 |
| Extremely Inverse (EI) | 80 | 2.00 | 1.00 |
| Long Time Inverse (LTI) | 120 | 1.00 | 1.00 |

In any power system, a primary protection has its own backup one for guaranteeing a dependable power system. The two protective systems (primary and back-up) should be coordinated together. Coordination Time Interval (CTI) is the criteria to be considered for coordination.

It's a predefined coordination time interval and it depends on the type of relays. For electromagnetic relays, CTI is of the order of 0.3 to 0.4 second, while for numerical relay, it is of the order of 0.1 to 0.2 second [26, 27]. To ensure the reliability of the protective system, the backup scheme shouldn't come into action unless the primary (main) fails to take the appropriate action. Only when CTI is exceeded, backup relay should come into action. This case is expressed as:

$$T_{Backup} - T_{Primary} \geq CTI \tag{14}$$

Where, $T_{Backup}$ is operating time of the backup overcurrent relay, and $T_{Primary}$ is operating time of the primary overcurrent relay.

## 5. Case Study: Simulation Results and Discussion

The proposed methodology is applied to an actual Algerian medium voltage (10 kV) meshed distribution power system at Constantine aliment by three substations 60/10 kV which is shown in Figure 5. This system has 7 bus, 6 distribution line and 8 load points. The all RDG's study is installed between buses 2 and 3. The parameters are in Appendix.

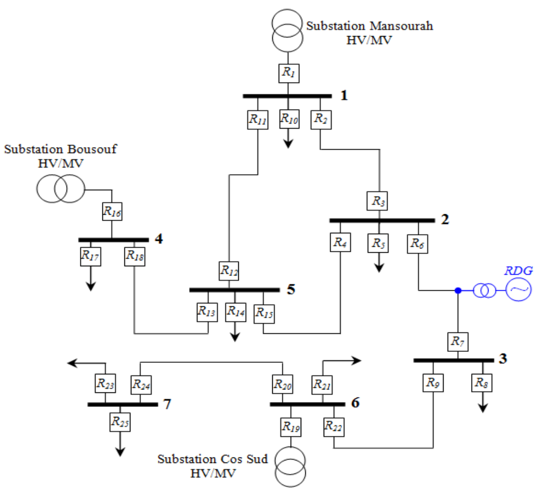


Figure 5. Radial Constantine Distribution Network

Figure 6 is shows caracteristic curve for IDMT ouvercurent relays No. 2 and 6 on absence of *RDG*.

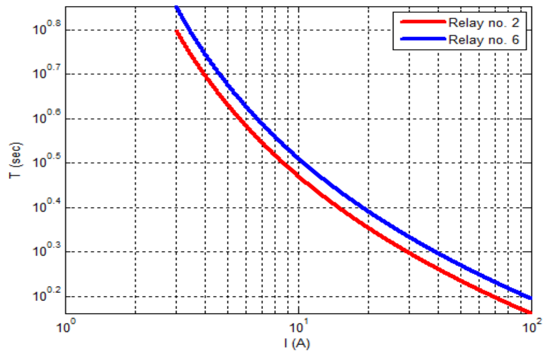


Figure 6. Characteristic Curve for Relays no. 6 and 2

From Figure 6, the coordination between two IDMT directional overcurrent relays No. 6 (primary) and No. 2 (backup) is respected. Figure 7 is shows impact of RDG location varied between buses *A* (0 km) to *B* (81.26 km) on chracteristic curve and operation time for IDMT ouvercurrent relays no. 6, where curve type is Normal Inverse (NI) for three power injected by RDG (0.5, 1.0 and 1.5 MW), where the fault at bus *B*.

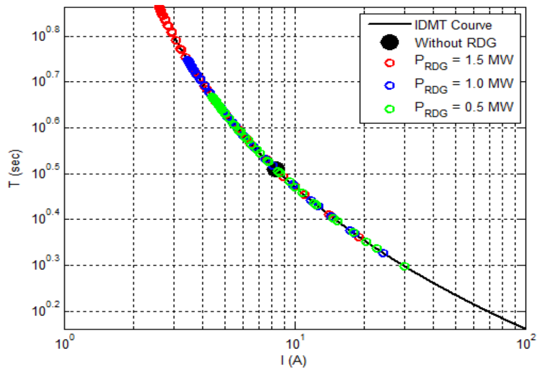


Figure 7. Impact of $d_{RDG}$ Variation on Characteristic Curve

Following Figure 7, the presence of RDG directly affected the value of fault current and thus the value of operating time will be affected either increased or decreased depends on the locality of RDG on MV distribution line. Figure 8 is shows impact of RDG location on fault current, and Figure 9 represent impact of fault current on operation time in the presence three RDG injected different power and installed in different location.

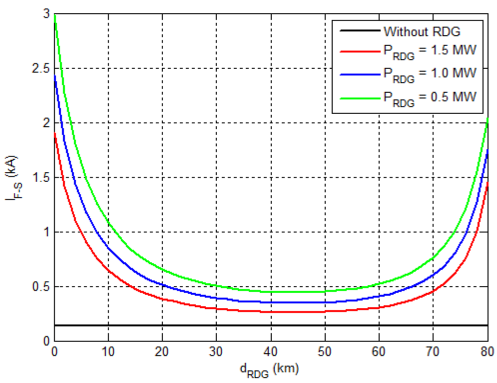


Figure 8. Impact of $d_{RDG}$ on Fault Current Measured by Relay

From Figure 8, regardless of the RDG location, the fault current value will always be greater contribution by a fault current value without RDG, whatever the power injected by the RDG. In the presence of RDG, the fault current is the maximum value if RDG located at the tip of the distribution line and fault current is minimum value if RDG box located in the middle.

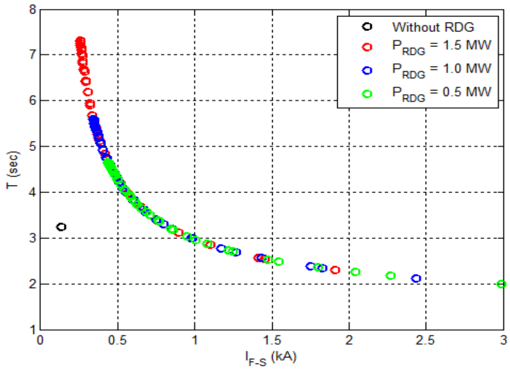


Figure 9. Impact of fault Current on Operation Time

From Figure 9, whatever the location and power injected by RDG the fault current will be changed and also the operation time of the circuit breaker. Figures 10 and 11 is shows impact of location of RDG on CTI valeu and ISC level index repectively in the presence three RDG.

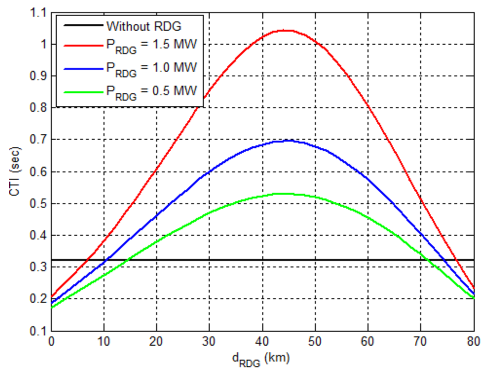


Figure 10. Impact of $d_{RDG}$ on CTI.

The result is shown in Figure 10 and it can be seen clearly that the $d_{RDG}$ has an impact on the CTI value (increase and descries compared in the case without RDG) is portaged in three zone. Existed three critical zones value of $d_{RDG}$ and CTI represented in Table 2.

Table 2. Critical Zone for RDG Location

| | | $d_{RDG}$ (km) | | |
|---|---|---|---|---|
| $P_{RDG}$ (MW) | | 0.5 | 1.0 | 1.5 |
| *Zone 1* | | [0 - 6.87]<br>[76.67 - 81.26] | [0 - 10.35]<br>[74.35 - 81.26] | [0 - 14.48]<br>[71.37 - 81.26] |
| *Zone 2* | *min* | 6.88 | 10.36 | 14.49 |
| | *max* | 76.66 | 74.34 | 71.36 |
| *Zone 3* | | [6.89 - 76.65] | [10.37 - 74.33] | [14.40 - 71.35] |

From this table, in the first and third zone, the CTI value in the presence RDG is increase and decrease compared with case without RDG, problem of mis-coordination between primary and backup relay. In the second zone, the CTI value is constant in the case without and with RDG, this location is the best.

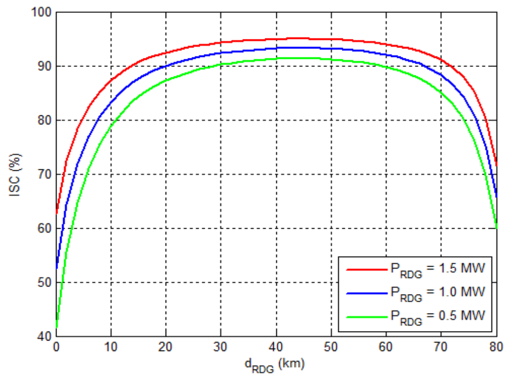


Figure 11. Impact of $d_{RDG}$ on ISC Level Index

From Figure 11, the ISC level index is maximum value if RDG localized in the middle of the line and minimum value box RDG located at the end of the MV distribution line.

## 6. Conclusion

This paper fills a gap in the understanding of the particular problem of protection blinding through presenting a detailed study of the impact of location RDG on IDMT directional overcurrent protection using a typical MV distribution network in presence three phase fault.

The factors that can influence the effect of RDG on the fault courant, operation time, CTI value and ISC level index for directional overcurrent protection system have been carefully considered and incorporated in the investigation. These factors include RDG capacity level, RDG location and fault location. By installing RDG in MV power distribution networks, the fault current levels are changed and may lead to some mis-coordination in directional overcurrent protection. The variation in operating time for circuit breaker has been quantified for several scenarios and it has been demonstrated that these increased times cause significant problems. For all paper study impact of RDG location it is necessary considering the impact fault current and protection coordination limits.

For the continuity of this work, an off-line settings directional overcurrent relays in the presence RDG for different locality for meshed power systems are proposed application artificial neural network and heuristic algorithms. It is also recommended to develop an automation system based on the adaptive relay settings using optimization algorithms. This system can be adopted for determining the optimum settings of protection device and hence improve the quality of its operation relays.

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