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ON SOME TECHNICAL ASPECTS OF TRANSMISSION AND DISTRIBUTION NETWORKS INTERACTION

Izet Dzananovic[1], Sejid Tesnjak[2]

[1]Bosnian Power Utility, "Tuzla" Distribution Company, BOSNIA, E-mail: i.dzananovic@elektroprivreda.ba
[2]University of Zagreb, Electrical Engineering and Computing Department, Zagreb, CROATIA, E-mail: sejid.tesnjak@fer.hr

ABSTRACT
In this paper we analyze some technical aspects of the interaction between transmission and distribution systems that, in our view, could prove very important for power system operation within market environments, particularly for proper determination of the borders between the two subsystems. The interaction is analyzed through three problems: frequency control by controllable loads, voltage optimization and control in transmission system by reactive power compensating devices installed in distribution system, and the need for better reliability analysis for distribution systems. All three problems are supported with simulation results obtained with the help of a synthetic five-bus test system.

KEY WORDS
Transmission system, distribution system, interaction, optimization, control, reliability.

1. Introduction

Electricity sector deregulation and introduction of electricity markets, brought new relations among involved participants. Unbundling vertically organized power utilities into horizontally organized legal subjects imposes new operational conditions in this sector.
The new relations among transmission and distribution networks, after establishing new legal subjects, has been and continues to be a research topic of paramount importance. The need for optimal power system operation, as a technologically integrated system, imposes that the modes of interaction and their intensity have to de properly defined as well as arrangement of the technical, legal, and economical relations among newly established transmission and distribution subjects
The problem of these interactions is in the focus of this work with the main aim to raise the importance of this issue and suggest some technical aspects that could be decisive in this respect. Certainly there is no a panacea solution to this problem, but it is the authors hope that the results and observations given in the paper might prove helpful in further investigation of the same problem in each specific environment.

As the parts of technically integrated system the ways transmission and distribution system interact take on different forms and give raise to many phenomena that should be carefully investigated. Some of the technical problems have been studied in literature [1-4], but not as the technical problems important for the organization of the whole electricity business. We investigate three problems:

1. Frequency control by controllable loads in distribution system,
2. Possibilities for using reactive power compensating devices installed in distribution system to optimize and control the voltages in transmission system,
3. The need for better reliability analysis of distribution systems.

We also point out the importance of these problems for the organization of electricity sector, particularly in proper determination of the borders between transmission and distribution systems under authority of corresponding operators.
The paper is organized as follows: in Section 2 five-bus test system is presented, frequency control by controllable loads is illustrated in Section 3, in Section 4 a possibility of optimizing and controlling voltages in transmission system by compensating devices in distribution system and its impact on load tap changers (LTC) operation are demonstrated, while Section 5 draws some conclusions.

2. Five bus test system

The model of this test system is designed by the authors for wider research activities in the filed of the interaction between transmission and distribution systems. One-line diagram of the system is given in Figure 1, and approximately corresponds to the current situation in the part of Bosnian power system (the part near city of Tuzla). External system is modeled by Thevenin equivalent. Local system includes local power plant (modeled by one generator of 400 MW). Two load areas are modeled as load buses (buses 4 and 5 in Figure 1).

The load at bus 4 is modeled as static, voltage-dependent load with the coefficients of exponential model 1 for active power and 2 for reactive power [5,6] and equivalent asynchronous machine model [5,6]. At bus 5 the model of a small hydro power plant (10 MW) is included.

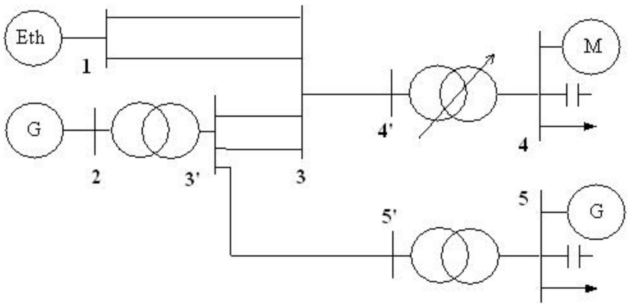

Figure 1. Five-bus test system

Local reactive power support is provided in distribution system only by capacitors placed in both load buses. The load at bus 4 is connected to the rest of the system through LTC transformer while the transformer at bus 5 is fixed-ratio device.

3. Frequency control by controllable loads

Frequency control is usually achieved by primary generator regulators and secondary level of the control (automatic generation control, AGC). In market environments certain generators accept this obligations as a part of providing ancillary services [7,8].On the other hand it is well known that generating units exhibit much better performances if not forced to often change their production level, or in other words not participating in providing this specific ancillary service. One of possibilities is to use the load for this purpose, instead of at least some generating units [7,8], of course if the load allows smooth enough changes. The change in load can be achieved by using control law,

$$\Delta P = K \cdot \Delta f \tag{1}$$

where Δf is frequency change at the load supply point and K is the system constant [7,8].
It is hard to achieve a continuous change in the load but change in small enough blocks is feasible. The system response, in terms of system frequency, for the case of both lines between the buses 1 and 3 (see Figure 1) trip is illustrated in Figure 2. The active power of local generator is given in Figure 3.
Speed governor installed at local generator is able to stabilize system. However, the frequency at the new equilibrium is lower than the nominal. The system response with the load control, in small enough blocks, is given in Figures 4 (frequency) and 5 (active power of local generator). Observe that the frequency returns to nominal value owing to the control action and at the same time local generator operates with a smaller change in active power (a change in active power is due to action of local speed governor).

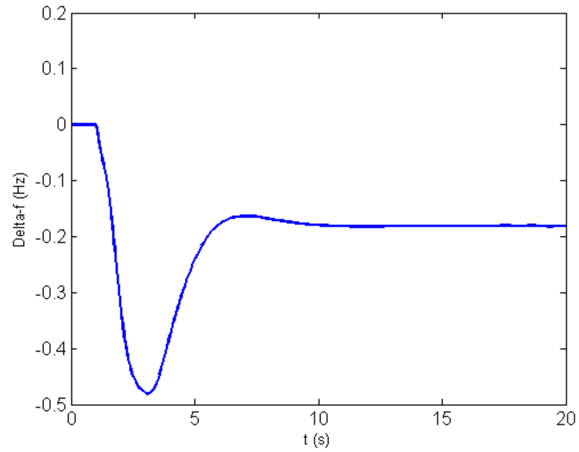

Figure 2. Frequency change

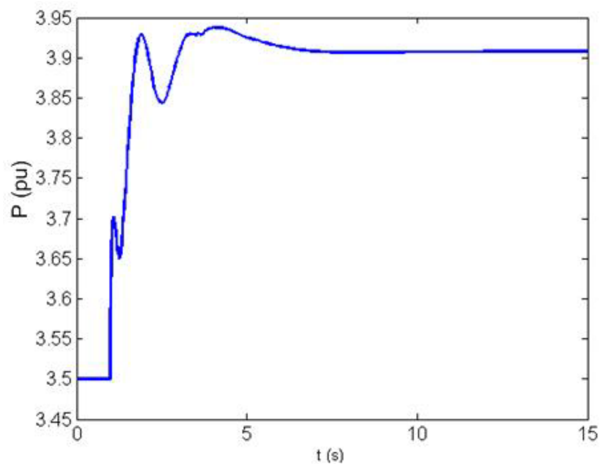

Figure 3. Local generator active power change

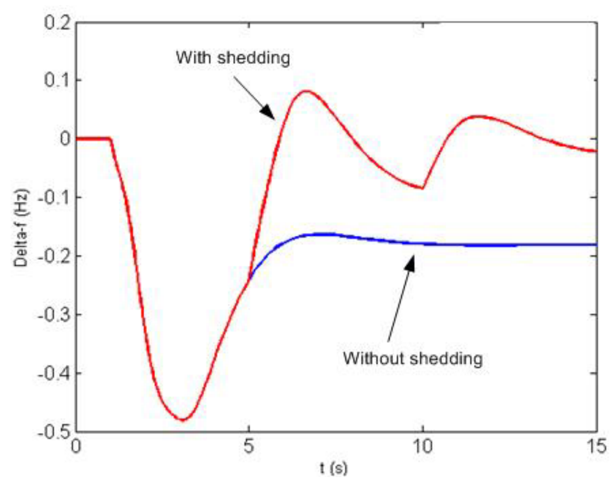

Figure 4. Frequency change with and without load control

The shedding, in Figures 4 and 5, corresponds to the load decrease (we rather call it shedding than decrease since it correspond to the changes in small blocks supposed to be 1 MW in the simulations), in small blocks, according to the control law (1).

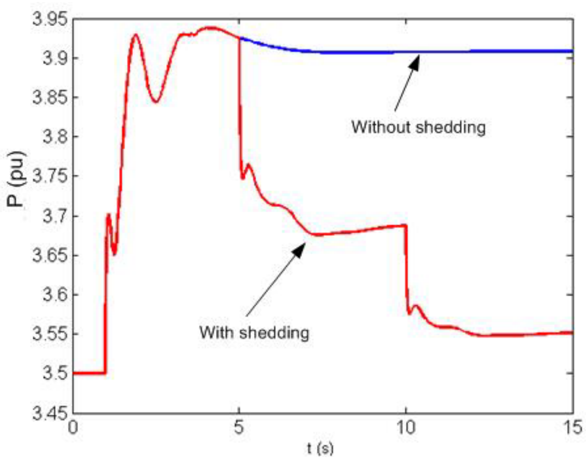

Figure 5. Local generator active power with and without load control

4. Transmission voltages optimization and control by distribution compensating devices

It is well known that reactive power sources installed over transmission system, in general, lower active power losses and improve voltage profile in the system. The aim of this section is to demonstrate and justify transmission voltage control by reactive power sources installed in distribution system. Of course it is possible to install these devices in distribution system with primary aim of supporting either distribution or transmission voltages. In both cases the devices have a positive impact to the both voltages. Indeed, for the purpose of improving transmission voltages it is better to chose and monitor a bus voltage at transmission side and vice-versa. The system responses for two cases, i.e. when the voltage is monitored at distribution side and threshold set to 0.94 pu, and when transmission voltage is monitored with the threshold of 0.9 pu, are given in Figure 6. Two capacitors (4 MVAr) are supposed to be installed at the distribution side for presented simulations.

The results clearly demonstrate that it is better to have reactive power sources installed in distribution system and to monitor a voltage in transmission system. This solution is more effective from economy point of view since installation of the reactive power sources in distribution system does not require adaptation transformers thus lowering investment costs dramatically.

Figure 7 presents a comparison of the system responses with reactive power sources in distribution system acting in two steps and one reactive source (10 MVAr) installed in transmission system. Clearly, the system response with reactive sources in distribution system offer smoother voltages. In addition, it offers a smaller number of tap changes of LTC extending life-time of this otherwise expensive device (for tap actions less for the case of having reactive capacitors in distribution system.

The disturbance considered for the simulations illustrated in Figures 6 and 7 is the trip of one of two (long) transmission lines between the buses 1 and 3 in Figure 1.

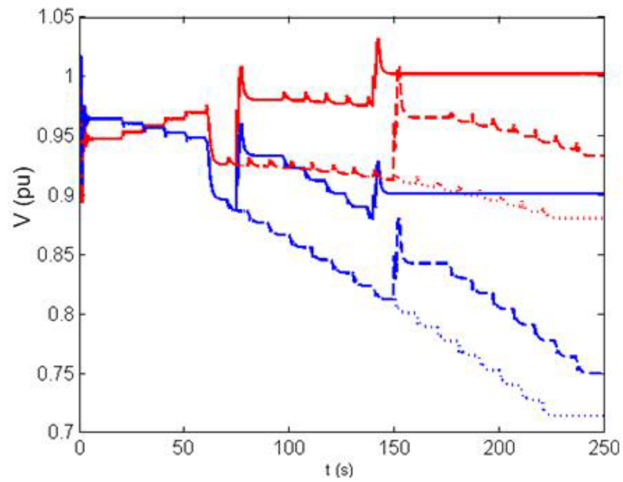

Figure 6. The system response for different monitored voltages

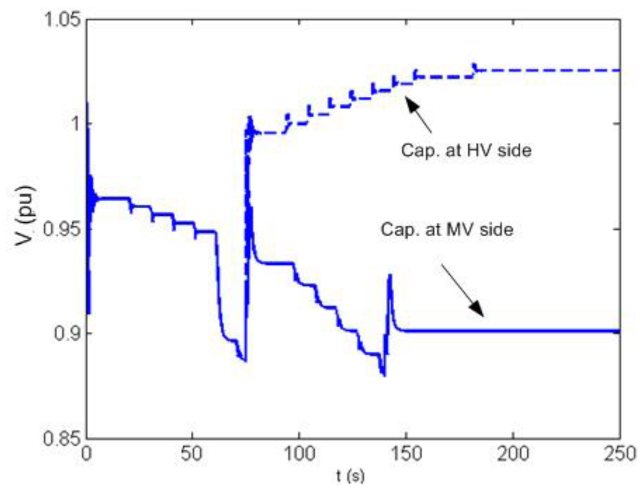

Figure 7. The system response for different placement of compensating devices

In order to make a fair comparison of the responses one needs to define a performance index and check for which response the index is better. In this paper we suggest following index of performances,

$$J = \begin{cases} \sum_{t=1}^{T}\sum_{n=1}^{N}\left(V_n(t) - V_n^{\max}\right)^2 & za \quad V_n(t) \geq V_n^p \\ \sum_{t=1}^{T}\sum_{n=1}^{N}\left(V_n^{\min} - V_n(t)\right)^2 & za \quad V_n(t) \leq V_n^p \end{cases} \tag{2}$$

where V_n^p is pre-specified (desired) voltage, $V_n^{\max}$ and $V_n^{\min}$ are maximal and minimal value of the voltage at bus n.

Summation in equation (2) is over all the buses in the system (both transmission and distribution) or several representative buses over the time interval T. For the cases given in Figure 7 the value of the index are **950** for the case of one reactive capacitor in transmission system and 867 for the case of two smaller reactive capacitors in distribution system.

5. The need for improved reliability analysis

Power system reliability is certainly the issue of paramount importance also in new market-driven environments. In order to achieve a satisfactory level of reliability there is a need to periodically maintain the system equipment. A tradeoff between the cost of maintenance and reliability is a challenging task in market environments. In this paper we identify some drawbacks in reliability assessment of distribution system used in practice until now and suggest that reliability-centered maintained [9] scheduling is right approach for the problem. The main problem we see in this context is the fact that reliability analysis of the primary distribution networks has been separately considered from the reliability of the distribution substation connecting distribution and transmission systems. This problem has been recognized and some research activities undertaken to solve the problem [9-12]. Most definitely, taking into account the reliability of distribution substation in distribution system analysis is an important improvement toward better reliability of the system in market environments. In addition, we believe that the reliability analysis should not be separated form optimal maintained scheduling and suggest the reliability-centered maintenance [9] is as a right approach. This approach is generally applicable for both system operators (transmission and distribution). In this paper we do not elaborate or suggest overall procedure but rather present some of the results related to the procedure:

- analysis of the influence of distribution substattion on primary network reliability,
- identification of the critcal components within the substation by sensitivity analysis,
- a comparison of the two simple maintnance strategies with resepct to the identified most influential component.

The results of sensitivity analysis in critical component identification are given in Figures 10 and 11. The sensitivities are determined for SAIFI (Figure 10) and SAIDI (Figure 11) reliability indices [10] by artificially introducing the change in parameters of 2% and calculating the change of corresponding index. Numbers in Figures correspond to: 1 (HV disconnecting switches), 2 (HV breakers), 3 (transformer), 4 (LV bus), and 5 (LV breakers). The results clearly indicate that the reliability is most sensitive to the changes in LV breaker parameters.

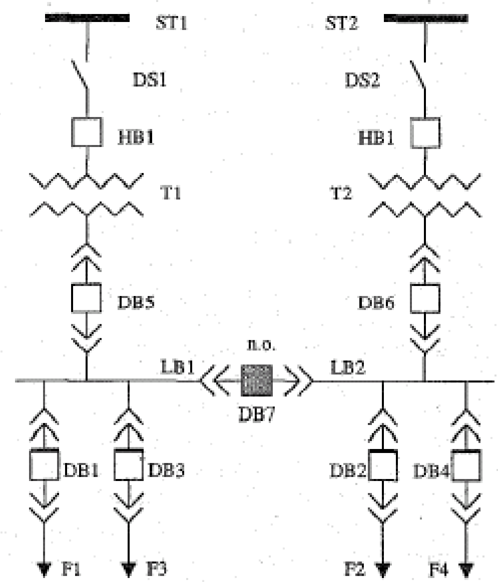

Figure 8. Substation layout

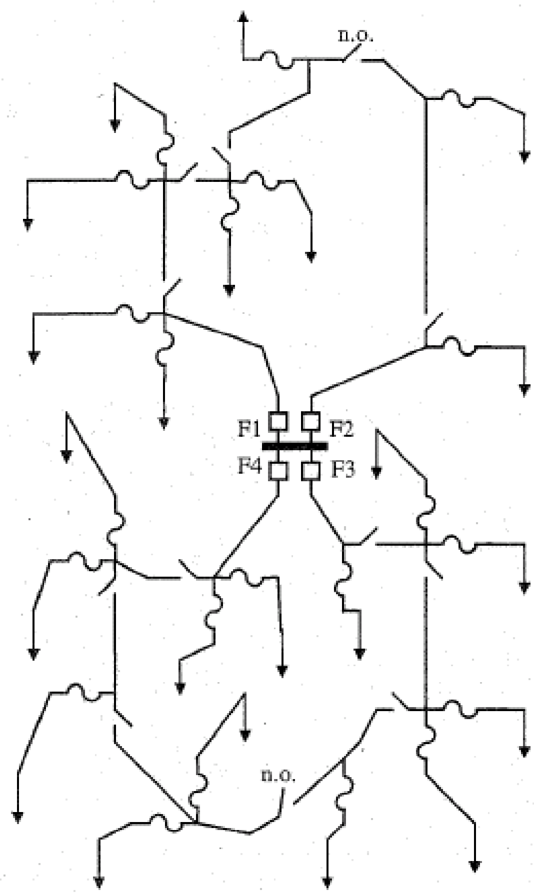

Figure 9. Distribution system at bus 2 of standard IEEE reliability test system [10]

For these purposes, we assume the same layout of the substation as in [10] and given in Figure 8. We also assume the same distribution network configuration as in bus 2 of the standard IEEE reliability test system, illustrated in Figure 9. The data used are the same as those given in [10].

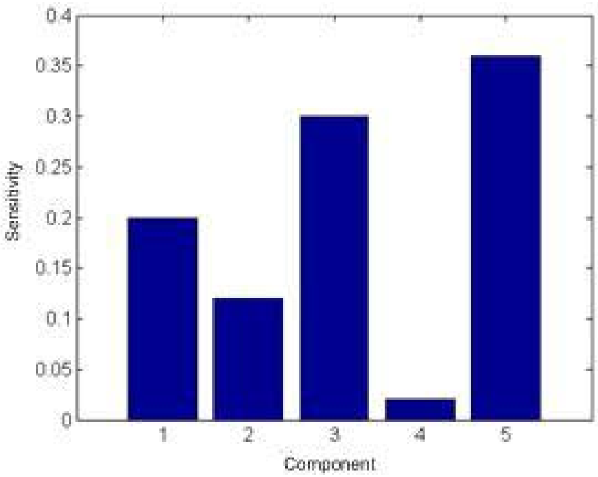

Figure 10. SAIFI index sensitivities

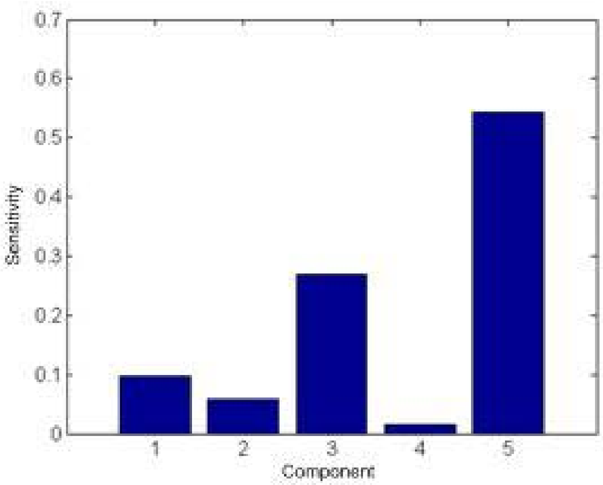

Figure 11. SAIDI index sensitivities

In order to illustrate the choice of maintenance strategy for LV breakers two for these strategies are analyzed:

- Strategy 1: Regular yearly maintenance without the breaker replacement,
- Strategy 2: Regular yearly maintenance with the replacement of both LV breakers in the fifth year of planning horizon.

The results are given in Figure 12, together with no-maintenance dash-dot curve). Solid line in Figure 12 corresponds to Strategy 1 and dashed to Strategy 2.

The choice for maintenance strategy for particular case is based on brute force approach since the number of variants is small (i.e., calculate total costs for planned period and compare them). The results are given in Figures 13 and 14, and obtained assuming the price for breaker 10,000.00 EUR, breaker maintenance costs of 300.00 EUR, and unnerved energy costs of 0.15 EUR/kWh.

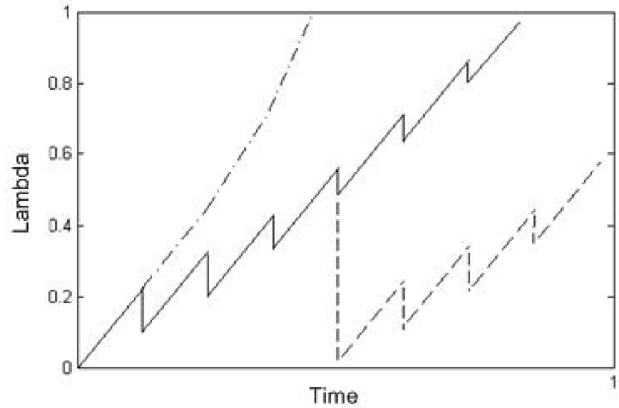

Figure 12. λ for different maintenance strategies

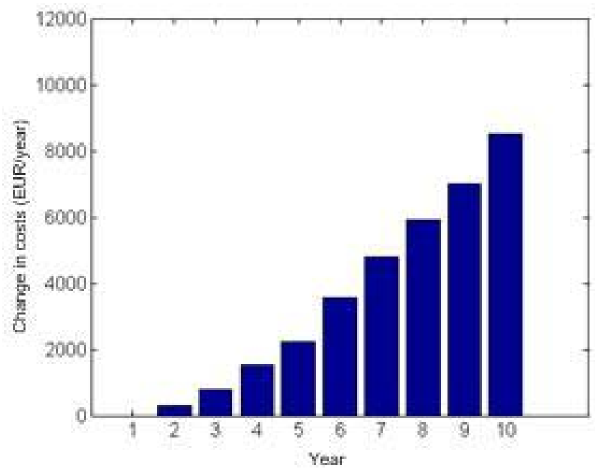

Figure 13. Change in costs for Strategy 1

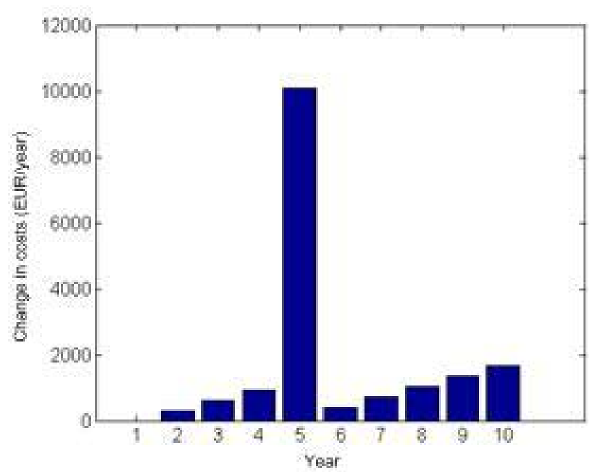

Figure 14. Change in costs for Strategy 2

The results in Figure13 correspond to the Strategy 1, while Strategy 2 results are given in Figure 14. One can observe that Strategy 2 offers better maintenance strategy for particular case. Indeed, this is not general conclusion but the aim of this section is to emphasize the problem and just suggest a possible direction for future investigations.

6. Conclusion

We presented in this paper analysis of three specific technical problems related to the interaction between transmission and distribution system. The emphasis has been put on the need for border determination between the two sub-systems of technologically integrated system, and demonstrated by simulations on a small test system, how analyzed problems could influence and prove very important in further solving of this problem. The results included in this paper are preliminary and further work and analysis of other problems arising between the two sub-systems will hopefully result in a clear determination of the borders and relations between transmission and distribution system operators. This is main aim of our future research activities.

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