COMPARATIVE STUDY OF STATCOM AND SSSC FOR IMPROVING POWER QUALITY

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Abstract

Reactive power compensation is an essential phenomenon in electrical power system. Essential component of the power system contains many equipment for its operation depends on the power transfer capability, voltage regulation and efficiency of transmission lines. In this study we are comparing STATCOM and SSSC for getting better result. The STATCOM is used for shunt compensation and SSSC is used for series compensation. A preliminary study was carried out to various types of FACT devices installation effect on power system stability and STATCOM and SSSC for stability analysis on the system developed using Fuzzy logic as a soft computing technique to increase the stability performance of our power system. After comparing the we found that SSSC damp the oscillation more quickly than STATCOM further we a adopt combined series and shunt FACT device operation in power system for getting satisfactory result which can be achieved by applying UPFC.

I. INTRODUCTION

The power system today is complicated network with hundreds of generating station and load centers being interconnected through transmission line. An electric power system can be subdivided into four stages as:

- Generation
- Transmission
- Distribution
- Utilization (load)

The basic structure of a power system is as shown in Fig 1.1 it composed of generating plants, a transmission system and distribution system. The interconnection of these substation is done through various transformers. Power Generation and Transmission is a complicated process, requiring the working of many devices of the power system in tandem to get the optimal output. One of the main objectives to get a major part is the reactive power in the power system and also it is required to maintain the voltage to deliver the active power through the lines. Loads like induction motor loads, dc motor load require reactive power for their operation. To improve the performance of power transmission lines, we need to control this reactive power in an efficient way and this is known as reactive power Compensation. Following are the aspects to the problem of reactive power compensation: load compensation and voltage problem. Load compensation consists balancing of real power drawn from the supply, improvement in power factor for better voltage regulation of large fluctuating loads. Voltage problem consists of reduction of voltage fluctuation at a given terminal of the transmission line. Following are the types of compensation can be used: series and shunt compensation. The phenomenon of compensation is to compensate the reactive power accurately as needed for example when the receiving end voltage is more it should absorb the additional voltage whereas if the receiving end voltage is less than the required it should deliver the required amount of voltage to the transmission line for better operation.

A. Flexible Ac Transmission Systems (FACTS)

In general, Flexible AC Transmission Systems (FACTS) is a new technology. It has the principle role of enhancing and power transfer capability in AC systems. This opportunity for controlling power and enhancing the usable capacity can be achieved by using FACTS devices. The possibility that current in a line can be controlled at a reasonable cost enables a large potential of increasing the capacity of existing lines with conductors, and use of FACTS controllers to enable corresponding power flow through such lines under normal and contingency conditions. These opportunities arise through the ability of FACTS Controllers to control the interrelated parameters that govern the operation of transmission systems including series impedance, shunt impedance, current, voltage, phase angle and the damping of oscillations at various frequencies below the rated frequency. The FACTS technology is not a single high-power Controller, but rather a collection of Controllers, A well-chosen FACTS Controller can overcome the specific limitations of a designated transmission line or a corridor. Because all FACTS Controller represent applications of the same principle, their production can be used to take advantage of microelectronic chips and circuits, the SCR or high power transistor is basic element for a variety of high power FACTS controllers.

B. *Classification of power system stability*

A Static Synchronous Compensator (STATCOM) is a member of the FACTS family that is connected in shunt with power system. The STATCOM consists of a solid state voltage source converter with GTO thyristor switches or other high performance of semi-conductor and transformer.

The fundamental principle of a STATCOM installed in a power system is the generation ac voltage source by a voltage source inverter (VSI) connected to a capacitor. The power transfer i.e. active and reactive between the power system network and the STATCOM is caused by the voltage difference across the reactance. The STATCOM can also increase power transfer capability of transmission lines, damping low frequency oscillation, and improving transient stability. The static synchronous compensator is represented by a voltage source; it is connected to the system through a coupling transformer. The voltage of the source is in phase with the ac system voltage at the point of connection, and the magnitude of the voltage is variable. The current from the source is limited to a maximum value by adjusting the voltage. Mathematical modelling and analysis of static compensator (STATCOM) is presented in. It explains the use of STATCOM for improvement of transient stability and power transfer.

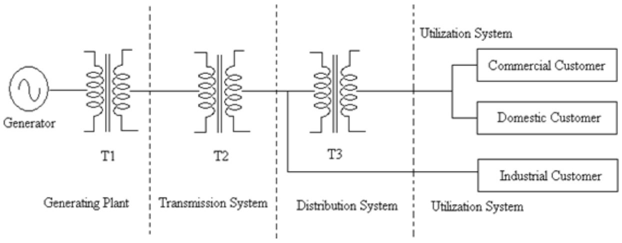

Fig.1 Basic Structure of Power System

II. LITERATURE SURVEY

Kamboj, N. ; Kumar, N. ; Singh, A. Here in this paper the damping of sub synchronous resonance is depicted. As we know that the use of series capacitor is very useful for reactive power compensation in transmission line. But it has a disadvantage that it leads to phenomenon of sub synchronous resonance in transmission line of power system. Sub synchronous phenomenon (SSR) is a condition where the electric network exchange energy at with the generator at one or more frequency below the synchronous frequency of the system. Hence in this paper it is explained to damp the oscillation caused by SSR. The SSSC damping characteristics are better than STATCOM .The results are obtained by modelling a linearalized system in MATLAB.

Amara, S. ; Hsan, H.A. In todays world the suppression of oscillation is electric power system is the need of the hour. The suppression can be done by many ways here in this paper the suppression is done by STATCOM that is static synchronous compensator, SSSC that is static synchronous series compensator and UPFC that is unified power flow controllers. For analysis under disturbance single machine infinite bus system was taken. The result reflects the performance of the devices on power system stability.

Chung T.S., Li Y.Z., A hybrid genetic algorithm–interior point method for optimal reactive power flow is presented. By combining a genetic algorithm (GA) with a non-linear Interior Point Method (IPM), a new hybrid technique for the Optimal Reactive Power Flow (ORPF) application is presented in that study.

The applied procdure can be essentially divided into two portions. The first portion is to solve the ORPF with the IPM by releasing the discrete variables. The second portion is to divide the original ORPF into two sub problems: continuous optimization and discrete optimization. The optimal solution can be obtained by solving separately the two sub-problems.

C. H. Liang, C. Y. Chung, K. P. Wong and X. Z. Duan.2010, there is a presentation of Parallel Optimal Reactive Power Flow Based on Cooperative Co Evolutionary Differential Evolution and Power System Decomposition. Differential evolution (DE) is an effective evolutionary technique for solving optimal reactive power flow issues, but it require a large population to prevent convergence in the suitable time.

Zarate, L.A.Ll. ; Castro, C.A. ; Ramos, J.L. M. ; Ramos, E.R., a presentation method for calculating the maximum loading point (MLP) and the voltage stability security limit of electric power networks. The presented technique depends on nonlinear programming methods. The MLP is accurately achieved after some demand change steps. The computational procedure has two kinds of power changes. Primary, load increases towards to the MLP are applied for reducing a fitness function based on sensitivities. In case an overestimated load increase moves the system outside the stable feasible operating region, another very simple optimization-based process lead to minimize the power mismatches that to calculate the load adjustment curtailment to pull the system back onto the feasible area small sc.

Sode-YOME, N. Mithulananthan and K. Y. Lee.2010, the maximum loading margin (MLM) method is presented in determining generation directions to maximize the static voltage stability margin, where the MLM is calculated at different possible generation tends in the generation space. An easy and short formula indicating the link between the generation direction and the LM is applied to get the MLM point.

I. Smon, G. Verbi and F. Gubina.2008, the Telligent's theorem and adjoint networks are applied to get a good, local voltage-stability index. The new procedure makes it available to calculate the Thevenin's values in a various method than adaptive curve-fitting techniques, from two consecutive phasor measurements center or locally in a numerical relay.

Sheng Li ; Qi Zhao ; Cheng Chen ; Yan Xu., various control methods for damping undesirable inter-area oscillations by various FACTS devices are illustrated. The problem of oscillations is analyzed from Hopf bifurcations perspective. It is seen that the damping introduced by the SVC and STATCOM controllers with only voltage control was lower than that provided by the PSSs and the STATCOM provides better damping than the SVC as this controller is able to transiently exchange active power with the system membership functions for the input and the output variables. The genetic algorithm is applied to optimize the scaling factors these are used in the scaling portion of the fuzzy controller. After that simulation is applied on four machines interconnected power system, which used as a test system installation of FACTS devices related to voltage stability and losses issues. It concerns with determining the optimal location of FACTS devices.

Zabaiou, T. ; Dessaint, L.-A. ; Kamwa.I., There is a proposal for a recent optimal technique to minimize power loss and at the same moment to enhance the voltage stability in radial networks. The resultant characteristics of this research can be presented as follows.

- An powerful a voltage stability index (VSI) has been applied to determine the voltage stability that is more suitable for constant switching characteristics.
- The method can use both dual and single optimization based on operational conditions priority, which may be ill conditions distribution system, utility can adapt the network configuration by the VSI only, or dual optimization for VSI and loss minimization.
- In addition to, the improved branch exchange (IBE) approach is presented to decrease the computational time. The IBE approach depends on the losses determination index.

Brusilowicz, B. ; Rebizant , W. ; Szafran, J., a new criterion of voltage stability margin is proposed. Voltage instability is usually leading to participating in the disturbances progress of power networks. While raising of load admittance, bus voltage fall to certain limit, which the total power (V2Y) does not go up. margin start to be low, and has bad effects on the large-scale power system disturbance. For executing that, there is a plan to make automatic apparatuses.

III. POWER FACTOR CORRECTION AND ITS APPLICATIONS

A. *Overview*

We need to know the importance of power factor correction and its applications and also the importance of reactive planning in distribution and transmission systems. There are several quantities related to power. It is very important to have a quick overview on these terms and/or definitions. The definitions listed below are taken from IEEE Std 1996, "The IEEE Standard Dictionary of Electrical and Electronics Terms-Sixth Edition."

B. *Active power*

The time average of the instantaneous power over one period of the wave. For sinusoidal quantities in a two-wire circuit (single-phase system), it is the product of the voltage, current, and cosine of the phase angle between them. For balanced three-phase circuits, the total active power is three times of the active power for each terminal (phase).

C. *Reactive power*

For sinusoidal quantities in a two-wire circuit, reactive power is the product of the voltage, current, and sine of the phase angle between them. In a passive network, reactive power represents the alternating exchange of stored energy (inductive or capacitive) between two areas.

D. *Apparent power*

For sinusoidal quantities in either single-phase or three-phase circuits, apparent power is the square root of the sum of the squares of the active and reactive powers.

E. *Power factor*

The ratio of the total active power in watts to the total apparent power in volt amperes.

F. *Power factor angle*

The angle whose cosine is the power factor.

G. *A power triangle*

A power triangle, or *P-Q triangle*, is obtained by drawing a line proportional to the active power on the real axes and a line proportional to the reactive power following it (a) up by 90 degrees for a lagging power factor (inductive loads) or (b) down by 90 degrees for a leading power factor (capacitive loads). Then by adjusting the starting and ending points (this length is proportional to the apparent power) to form a power triangle. In short, a power triangle is a right triangle consisting of active power, reactive power and apparent power. Since most of loads have lagging power factor, the analysis of compensating from a leading power factor load is impractical; therefore, it is beyond the scope of this material. If such a need occurs, the method presented here can still be helpful. From geometry, the three edges of a right triangle have a very important relation By Pythagorean theorem,

$$S^2 = P^2 + Q^2$$

Either one of these equations is useful to explain the idea of power factor correction. First of all, for a pure resistive load, where the reactive power is zero. Therefore, S = P, and power factor is 1, or unity. Other than pure resistive loads if an inductive load is present, the amount of its reactive power will determine its power factor, the greater the reactive power the lesser the power factor. This can be seen from the above equations, the greater the reactive power, the greater the apparent power while the active power demand the same. Hence the power factor, the ratio of active power to apparent power, is lesser. We can use power factor angle to visualize the above observation. When the load is drawing more reactive power, the power angle will be larger. The larger the power factor angle, the lower its power factor will be observed power factor is the cosine of the power factor angle.

H. *Power Factor Correction*

Since the power bill is based on the usage of the active power kilo-watt-hour (kWH) while the power system equipment is built to handle the apparent power, the power companies may charge a higher rate for loads drawing below a certain power factor, for instance, 0.95. It is mainly applied to large industrial loads/customers. Power factor penalties differ from one company to other. The penalties serve the important function of providing incentive to customers for power factor corrections. By spending required amount of money on power factor correction at the front end, customers can save money on lesser power payment every month. Therefore, in a long run it is very economical from customer point of view .It is very important to know the economics of power factor correction.

I. *Power System Stability*

The importance of power system stability is increasingly becoming one of the most limiting factors for system working. Therefore by the stability of a power system, we mean the ability of the system to remain in operating equilibrium state, or in synchronism, while the system is subjected to a disturbance. Following are the types of stability, termed as steady state, dynamic and transient stability. However, to understand the basic concepts of power systems stability, only the transient stability with simplified system will be presented in this module.

J. *Stability Definitions:*

In the study of electric power systems, following different types of stability descriptions are encountered. There are three types of stability, termed as

a) Steady-state stability – Refers to the stability of a power system subject to small and gradual changes in load, and the system remains stable with conventional excitation and governor controls.

b) Dynamic stability – Refers to the stability of a power system subject to a relatively small and sudden disturbance, the system can be described by linear differential equations, and the system can be stabilized by a linear and continuous supplementary stability control.

c) Transient stability – Refers to the stability of a power system subject to a sudden and severe disturbance beyond the capability of the linear and continuous supplementary stability limit, and the system may lose its stability at the first swing unless a more effective countermeasure is taken, usually of the discrete type, such as dynamic resistance braking or fast valuing for the electric energy surplus area, or load shedding for the electric energy deficient area. For transient stability analysis and control design, the power system must be described by nonlinear differential equations.

K. *Fundamentals of Transient Stability:*

Transient stability concerns with the matter of maintaining synchronism among all generators when the power system is suddenly subjected to severe disturbances such as faults or short circuits caused by lightning strikes, the sudden removal from the transmission system of a generator and/or a line, and any severe shock to the system due to a switching operation. Because of the severity and suddenness of the disturbance, the analysis of transient stability is focused on the first few cycles, following the fault occurrence or switching operation. First swing analysis is another name that is applied to transient stability studies, since during the brief period following a severe disturbance the generator undergoes its first transient overshoot, or swing. If the generator(s) can get through it without losing synchronism, it is said to be transient stable. But, if the generator(s) loses its synchronism or parallelism and cannot get through the first swing, it is said to be (transient) unstable.

There is a critical angle within which the fault must be cleared if the system is to remain stable condition. The equal-area criterion is required and can be used to understand the power system stability.

IV. SIMULATION MODEL DESCRIPTION

To understand the output of the simulation we have firstly considered a system in which we have not included STATCOM and SSSC and we go through the output of the whole system. We have a variable input voltage and without STATCOM and SSSC, the output varies unevenly and the three factors we are considering varies very much. Due to this we understand the need of a simple Capacitor bank or FACTS devices so that proper reactive power can be injected and we get the output stable, again we consider the output stability in terms of three factors Settling time, Peak Variation & regulation. Now further to make sure that the output is more stable we introduce Fuzzy logic controller and then we see the output variation. To a great or extent the output parameters are stabilized and we see the settling time going down, the peak variation going down and regulation increasing. This indicates that by using the STATCOM and SSSC and with the use of Fuzzy logic controller output can be stabilized. We have taken 3 cases to study in detail the outcome of using STATCOM and SSSC with fuzzy logic controller.

A. *System Modeling*

The complete system has been illustrated in terms of Simulink blocks in a single integral model. Among all one of the important features of Simulink is it being interactive, which is seen by display of signal at each terminal. A parameter within any block can be controlled from a MATLAB command line or through an m–file program. This is helpful in transient stability analysis as the power system configurations differ before, after and during the fault. Control measures and loading conditions can also be implemented accordingly.

B. *Mathematical modeling*

Once the **Y** matrix for each network condition (pre-fault, during and after fault) is evaluated, we can eradicate all the nodes except for the internal generator nodes and obtain the **Y** matrix for the reduced network. This reduction in network can be achieved by matrix operation with the fact in mind that all the nodes have zero injection currents except for the internal generator nodes.

In the first part of our thesis we designed a power system with single source of 230 KV/ 100 MVA with transmission lines up to 800 Km. long. The source is connected at one end of the line & load is connected to the other end of the line. A STATCOM and SSSC connected at one center of the line (at 400KM from source) the rating of STATCOM and SSSC is 100 MVA at 230 KV.

Now the step is used to analyze the performance of STATCOM and SSSC to improve the system performance in terms of stability of voltage fluctuation with variation of load & with excessive reactive load. For load variation the line load from 25MVA is increased to 100 MVA in step of 25 MVA at line step of 20 cycles. In second scenario the reactive load of rating 50 MVA is switched to line. For both scenario the following parameters are measured and compared with & without STATCOM and SSSC.

1) Peak voltage swing.
2) Settling time.
3) Voltage variation at load.

In the second part of the thesis a fuzzy based controller is designed for same. STATCOM and SSSC for the improvement of AC Regulation block in Simulink. Then the comparison is performed for same parameters as explained in first part. The fuzzy controller regulates the Iq ref according to it's input error voltage between measured & reference & change in error.

The STATCOM and SSSC Voltage regulator employs PI Controller, which is both economical and simpler. Hence, the PI controller is utilized in most of the current industrial applications. However, this controller fails when the controlled object is highly nonlinear and uncertain. Therefore, an idea is proposed to combine the PI controller along with a Fuzzy logic based controller, in order to keep the benefits of PI controller and thereby overcome its disadvantages too. The Fuzzy Logic is a rule based controller, where a set of rules represents a control decision mechanism to correct the effect of certain causes coming from power system. This approach utilizes qualitative knowledge of a system while designing the controller. The block diagram structure of Fuzzy controller is shown in Figure below.

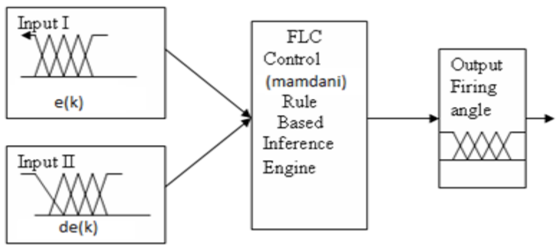

Fig.2 Fuzzy Controller

The inputs to the fuzzy system are voltage error and change of error, while its output is taken as the control signal and the synchronous firing pulses are provided to the thyristors by the pulse generators.

C. *Fuzzyfication*

Fuzzy set is a collection of distinct elements with a varying degree of inclusion or relevance. If X is a set of elements, then a fuzzy set A in X is defined to be a set of ordered pairs, $A=\{(x,\mu A(x))|\ x\ \varepsilon\ X\}$, where $\mu A(x)$ is called the Membership function (MF). MF is a curve which defines how each point in the input space is mapped to a membership value between 0 and 1.

D. *Rule-Base*

In the fuzzy model, the relationship between the input and output features are represented by IF premise THEN consequent. The fuzzy rules can be generated and framed with the help of an expert operator's experience and knowledge.

Rule 1: If voltage error, e(k) is low AND change of error de(k) is ok, then the output (Susceptance) is low.
Rule 2: If voltage error, e(k) is ok AND change of error de(k) is ok, then the output (Susceptance) is ok.

Rules used to output defuzzyfication is performed by centroid method. To understand the functioning of FACTS devices and the stability that we are calculating in this thesis it is necessary to understand the basics of reactive power compensation as given below in the second part of the thesis a fuzzy based controller is designed for same. STATCOM and SSSC for the improvement of AC Regulation block in Simulink. Then the comparison is performed between STATCOM and SSSC for same parameters as explained in first part. For load variation the line load from 25MVA is increased to 100 MVA in step of 25 MVA at line step of 20 cycles. The source is connected at one end of the line & load is connected to the other end of the line.

Inside the AC & DC voltage regulator we introduce the fuzzy logic controller. In the diagram below we can see firstly the simple STATCOM without fuzzy logic controller and then STATCOM with fuzzy logic controller. Capacitor bank or FACTS devices so that proper reactive power can be injected and we get the output stable, again we consider the output stability in terms of three factors Settling time, Peak Variation & regulation. Now further to make sure that the output is more stable we introduce Fuzzy logic controller and then we see the output variation. To a greater extent the output parameters are stabilized and we see the settling time going down, the peak variation going down and regulation increasing.

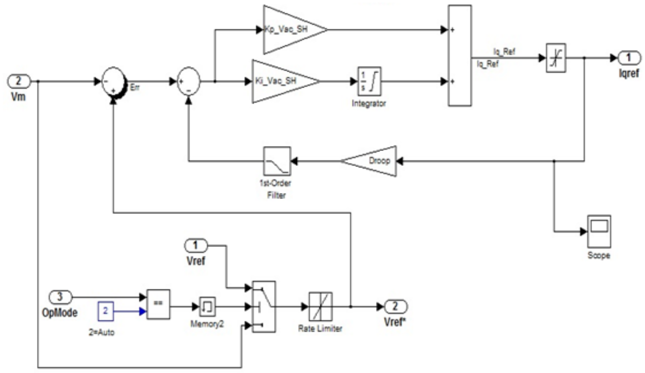

Fig.3 STATCOM without fuzzy controller

SSSC for the improvement of AC Regulation block in Simulink. Then the comparison is performed for same parameters as explained in first part. The fuzzy controller regulates the Iqref. According to it's input error voltage between measured & reference & change in error.

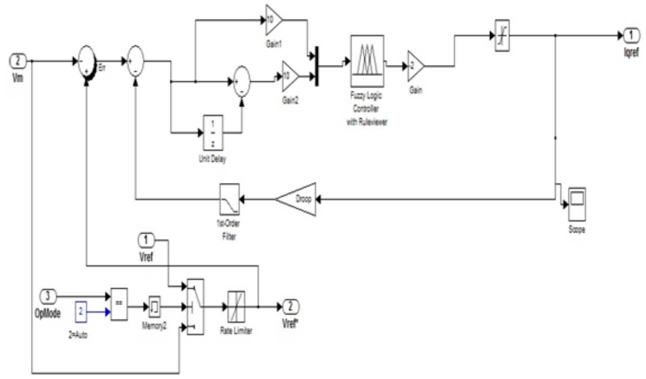

Fig.4 STATCOM with fuzzy controller

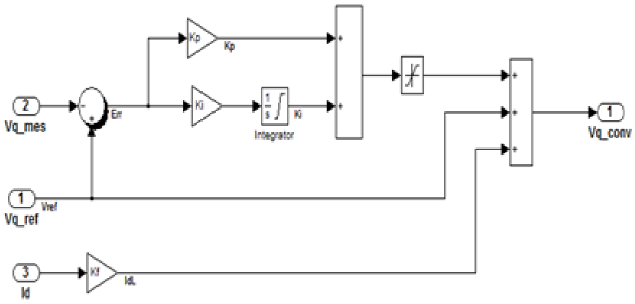

Fig.5 SSSC without fuzzy logic controller

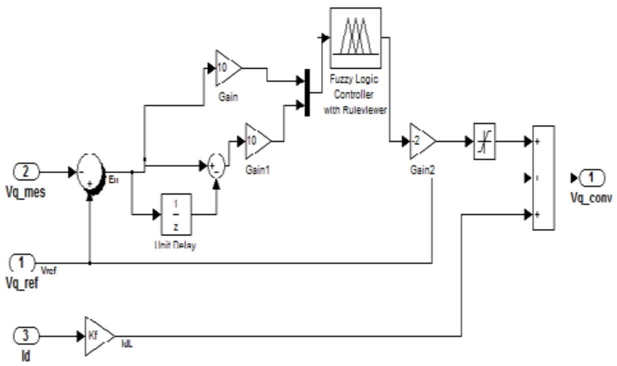

Fig 5.9 SSSC with fuzzy logic controller

The difference lies in the output of the fuzzy logic controller from the conventional STATCOM and SSSC device. The output will be more rectified and error free when fuzzy logic controller is introduced. The fuzzy controller regulates the Iq ref according to it's input error voltage between measured & reference & change in error.

V. CONCLUSION

In this work models are developed using fuzzy logic. A preliminary study was carried out to various types of FACT devices installation effect on power system stability. Then we took STATCOM and SSSC to look forward the stability analysis on the system. We then adopted Fuzzy logic as a soft computing technique to increase the stability performance of our power system. We then made a simulation model for the same. Results with more stability were obtained which prove our work. Then we compared the results .After comparing the we found that SSSC damp the oscillation more quickly than STATCOM. But there is a need for combined series and shunt FACT device operation in power system for getting satisfactory result which can be achieved by applying UPFC.

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