**International Journal of Science and Research (IJSR)**
**ISSN (Online): 2319-7064**
**Index Copernicus Value (2013): 6.14 | Impact Factor (2014): 5.611**

# Optimal Location of Shunt FACTS Devices for First-Swing Stability Enhancement in Inter-Area Power System

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**Abstract:** ***This paper deals with the location of shunt FACTS devices to improve transient stability in a long transmission line with predefined direction of real power flow. Shunt Flexible AC Transmission System (FACTS) devices, when placed at the mid-point of a long transmission line, play an important role in controlling the reactive power flow to the power network and hence both the system voltage fluctuations and transient stability. The validity of the mid-point location of shunt FACTS devices was verified using Simulink, with different shunt FACTS devices, namely static var compensator (SVC) and static synchronous compensator (STATCOM) in a long transmission line using the actual line model. It has been observed that the FACTS devices, when placed slightly off-centre towards sending-end, give better performance in improving transient stability and the location depends on the amount of local/through load. The results are experimented and simulated on MATLAB/Simulink environment.***

**Keywords:** Inter-area Power System, Transient Stability, First-Swing Stability, Shunt FACTS devices, SVC, STATCOM

## 1. Introduction

The basic operating requirements of an ac power system are that the synchronous generators must remain in synchronism and the voltages must be kept close to their rated values [6]. The capability of a power system to meet these requirements in the face of possible disturbances (line faults, generator and line outages, load switching's, etc.) is characterized by its transient, dynamic, and voltage stability. The stability requirements usually determine the maximum transmittable power at a stipulated system security level. The development of the modern power system has led to an increasing complexity in the study of power systems, and also presents new challenges to power system stability, and in particular, to the aspects of transient stability and small-signal stability[1]. Transient stability control plays a significant role in ensuring the stable operation of power systems in the event of large disturbances and faults, and is thus a significant area of research. This paper investigates the improvement of transient stability of a two-area power system, using Flexible AC Transmission System devices like Static VAR Compensator (SVC), Static Synchronous Compensators (STATCOM).

Recent break-throughs in power electronics technology have enabled the development of a variety of sophisticated controllers used to solve long-standing technical and economical problems found in electrical power systems at both the transmission and distribution levels. These emerging controllers are grouped under the headings FACTS and custom power technology respectively. FACTS is one aspect of the power electronics revolution that is taking place in all areas of electric energy. A variety of powerful semiconductor devices not only offer the advantage of high speed and reliability of switching but, more importantly, the opportunity offered by a variety of innovative circuit concepts based on these power devices enhance the value of electric energy. The use FACTS devices in a power system can potentially overcome limitations of the present mechanically controlled transmission systems. By facilitating the bulk power transfers, these interconnected networks minimize the need to enlarge power plants and enable neighboring utilities and regions to exchange power. The stature of FACTS devices within bulk power system will continually increase as the industry moves toward a more competitive posture in which power as bought and sold as a commodity. As power wheeling becomes increasingly prevalent, power electronic devices will be utilized more frequently to insure system reliability and stability and to increase maximum power transmission along various transmission corridors.

### 1.1 Literature Review

Recently network blackouts related to voltage collapse tend to occur from lack of reactive power support in heavily stressed conditions, which are usually triggered by system faults. Calvaer [2] stated that a system may undergo a voltage collapse if it includes at least one voltage collapse bus. Chebbo et al. [3] noted that the cause of the 1977 New York blackout was proved to have been a reactive power problem, and the 1987 Tokyo blackout was believed to have been due to a reactive power shortage and a voltage collapse during a summer peak load. However, reactive power has received less attention recently until the Great Blackout in August 2003 in the northeastern US, which showed that reactive power in US power systems was not very well planned and managed. Reactive power including its planning process has received tremendous interest after the 2003 Blackout from utilities, independent system operators (ISOs), researchers, and the government.

Power electronics based equipment, or Flexible AC Transmission Systems (FACTS), provide proven technical solutions to voltage stability problems. Especially, due to the increasing need for fast response for power quality and voltage stability, the shunt dynamic Var compensators such as Static Var Compensators (SVC) and Static Synchronous Compensators (STATCOM) have become feasible alternatives to a fixed reactive source, and therefore have received intensive interests. There are more than 50 SVCs installed in the United States, ranging from 30MVar to 650MVar each. STATCOMs are installed at several sites in the United States, ranging between 30MVar &100MVar each. FACTS make the application of a large amount of Var compensation more efficient, flexible, and attractive. Consequently, a series of questions have been raised frequently by utility planners and manufacturers: where is the right location and what is the right size for the installation of reactive power compensators considering technical and economic needs? Can the models, methods, and tools used for static Var planning be applied in dynamic Var planning? The answers to these questions are needed for utilities to make better use of these new power electronic controlled Var sources.

The mid-point sitting is most effective in reactive power control. The transmission line must be operating below the thermal limit and the transient stability limit. Tan, Y.L suggested a novel method for the analysis of the effectiveness of an SVC and a STATCOM of the same KVar rating for first-swing stability enhancement .The analysis shows that the STATCOM is superior to the SVC for first-swing stability enhancement [5]. Siddhartha Panda, Ramnarayan N. Patel investigated about the Shunt Flexible AC Transmission System (FACTS) devices, when placed at the mid -point of a long transmission line, play an important role in controlling the reactive power flow to the power network and hence both the system voltage fluctuations and transient stability.

### 1.2 Problem Statement

The stability problem is concerned with the behavior of the synchronous machines after they have been perturbed. If the perturbation does not involve any net change in power, the machines should return to their original state. If an unbalance between the supply and demand is created by a change in load, in generation, or in network conditions, a new operating state is necessary. In any case all interconnected synchronous machines should remain in synchronism if the system is stable; i.e., they should all remain operating in parallel and at the same speed.

This paper is organized as following the Introduction and literature survey, Section II illustrates the Two-area Power System Model. Section III presents brief details about Shunt FACTS devices such as Static Var Compensator (SVC), Static Synchronous Compensator (STATCOM) and Location of Shunt FACTS devices in Two-area Power System. Section IV presents the Result and analysis with SVC, STATCOM individually when a 3-ph fault occurred between bus bars $B_1$ & $B_2$. Section V concludes the paper.

## 2. Design of Study Model of Power System

An extended power system can be dividing into a number of load frequency control areas inter connected by means of tie-lines .Without loss of generality we shall consider a two area case connected by a single tie-line as illustrated in fig1. The two area system as proposed is modeled with two hydraulic generating units of 1400 MVA and 700 MVA, respectively, in each area, connected via a 500 km long transmission line as shown in Fig. 1 for our study [5, 7]. The two machines are equipped with a hydraulic turbine and governor (HTG), excitation system and power system stabilizer (PSS). Both SVC and STATCOM used for this model have the same rating of ±100 MVA and the reference voltage is set to 1 pu for both SVC and STATCOM. Initial power outputs of the generators are $P_1 = 0.7$ pu and $P_2 = 0.5$ pu and the SEP and REP with- out the FACTS device are 894 MW and 864 MW respectively. A three phase fault occurs at sending end bus at time t = 0.1s. The original system is restored upon the clearance of the fault.

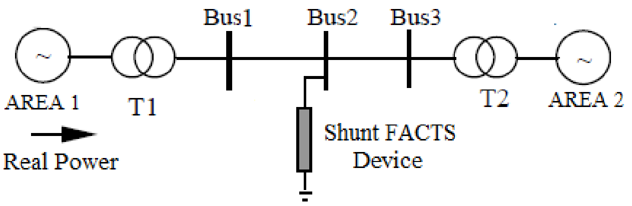


**Figure 1:** Two-area power system with FACTS device

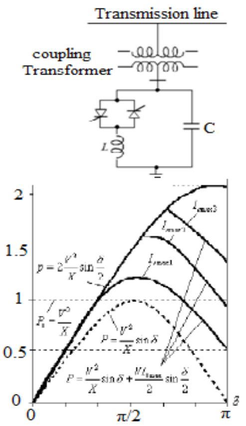
The transient following a system perturbation is oscillatory in nature, but if the system is stable, these oscillations will be damped toward a new quiescent condition. These oscillations however are reflected as fluctuations in the power flow over the transmission lines. If a certain line connecting the two groups of machines undergoes excessive power fluctuations, it may be tripped out by its protective equipment there by disconnecting the two groups of machines. This problem is termed the stability of the tie line, even though in reality it reflects the stability of the two groups of the machines. The shunt converter is able to generate or absorb controllable reactive power in both operating modes (i.e., rectifier and inverter). The independently controlled shunt reactive compensation can be used to maintain the shunt converter terminal AC voltage magnitude at a specified value.

## 3. Shunt Facts Devices

FACTS controllers may be based on thyristor devices with no gate turn-off or power devices with gate turn-off capability. FACTS controllers are used for the dynamic control of voltage, impedance and phase angle of high voltage AC transmission lines. The basic principles of the following FACTS controllers, which are used in the two-area power system under study, are discussed briefly [1].

### 3.1 Static Var Compensator (SVC)

Static var systems are applied by utilities in transmission applications for several purposes. The primary purpose is usually for rapid control of voltage at weak points in a network. Installations may be at the midpoint of transmission interconnections or at the line ends. Static Var Compensators are shunt connected static generators / absorbers whose outputs are varied so as to control voltage of the electric power systems. In its simple form, SVC is connected as Fixed Capacitor-Thyristor Controlled Reactor (FC-TCR) configuration as shown in Fig. 2(a). The SVC is connected to a coupling transformer that is connected directly to the ac bus whose voltage is to be regulated. The effective reactance of the FC-TCR is varied by firing angle control of the anti-parallel thyristors. The firing angle can be controlled through a PI (Proportional + Integral) controller in such a way that the voltage of the bus, where the SVC is connected, is maintained at the reference value.



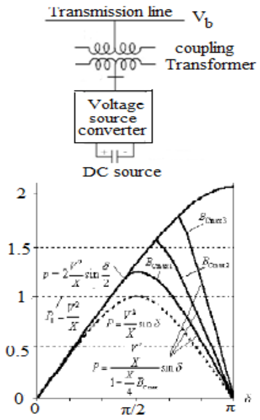


**Figure 2 (a):** SVC **Figure 2 (b):** STATCOM

### 3.2 Static Synchronous Compensator (STATCOM)

A STATCOM, controlled to regulate the terminal voltage, can increase the transient stability by maintaining the transmission voltage at the midpoint or some appropriate intermediate point in face of the increased power flow encountered immediately after fault clearing. However, the transient stability can be increased further by temporarily increasing the voltage above the regulation reference for the duration of the first acceleration period of the machine. The voltage increased above its nominal value will increase the electric power transmitted and thus will increase also the deceleration of the machine. This is illustrated in fig. 2(b), where the P versus δ plots of a simple two-machine system with different midpoint compensations represents the P versus δ is shown [5, 7]. The plot marked $P = 2V^2 \sin(\delta/2)/X$ plot obtained with an ideal compensator holding the midpoint voltage constant. The plots marked with STATCOM and SVC represents these compensators with a given rating insufficient to maintain constant midpoint voltage over the total range of δ. Thus, the P versus δ plots are identical to that of the ideal compensator up to a specific δ ($\delta = \delta_i$ ) at which the SVC becomes a fixed capacitor and the STATCOM a constant current source. In the interval between $\delta_i$ and δ, the P versus δ plots are those which correspond to a fixed midpoint capacitor and a constant reactive current source. The continuations of these plots in the $\delta_i$ to zero interval show the P versus δ characteristic of the two-machine system with the maximum capacitive admittance of the SVC and with the maximum capacitive output current of the STATCOM. That is angles smaller than $\delta_i$ the transmission line is overcompensated and for angles greater, it is undercompensated. This overcompensation capability of the compensator can be exploited to enhance the transient stability by increasing the var output to the maximum value after fault clearing.

### 3.3 Location of Shunt FACTS devices in Inter-area Power System

Previous works on the topic prove that shunt FACTS devices give maximum benefit from their stabilized voltage support when sited at the mid-point of the transmission line. The proof of maximum increase in power transfer capability is based on the simplified model of the line neglecting line resistance and capacitance. Based on the simplified line model it has been proved that the centre or midpoint of a transmission line is the optimal location for shunt FACTS devices. When the actual model of the line is considered, it is found that the FACTS device needs to be placed slightly off-centre to get the highest possible benefit. The mid-point sitting is most effective in reactive power control. The transmission line must be operating below the thermal limit and the transient stability limit. Siddhartha Panda, Ramnarayan N. Patel investigated about the Shunt Flexible AC Transmission System (FACTS) devices, when placed at the mid -point of a long transmission line, play an important role in controlling the reactive power flow to the power network and hence both the system voltage fluctuations and transient stability. This paper deals also with the location of a shunt FACTS device to improve transient stability in a long transmission line with predefined direction of real power flow. It has been observed that the FACTS devices, when placed slightly off-centre towards sending-end, give better performance in improving transient stability and the location.

## 4. Simulation and Results

### Case Study

The two area system as proposed in Section 2 is modelled with two hydraulic generating units of 1400 MVA and 700 MVA, respectively, in each area, connected via a 500 km long transmission line as shown in Fig. 3 for our study. The two machines are equipped with a hydraulic turbine and governor (HTG), excitation system and power system stabilizer (PSS). Both SVC and STATCOM used for this model have the same rating of ±100 MVA and the reference voltage is set to 1 pu for both SVC and STATCOM. Initial power outputs of the generators are $P_1 = 0.7$ pu and $P_2 = 0.5$ pu and the SEP and REP without the FACTS device are 894 MW and 864 MW respectively. A three phase fault occurs at sending end bus at time t = 0.1s. In order to maintain system stability after faults, the transmission line is shunt compensated at its center by a ±100 MVA SVC and STATCOM.

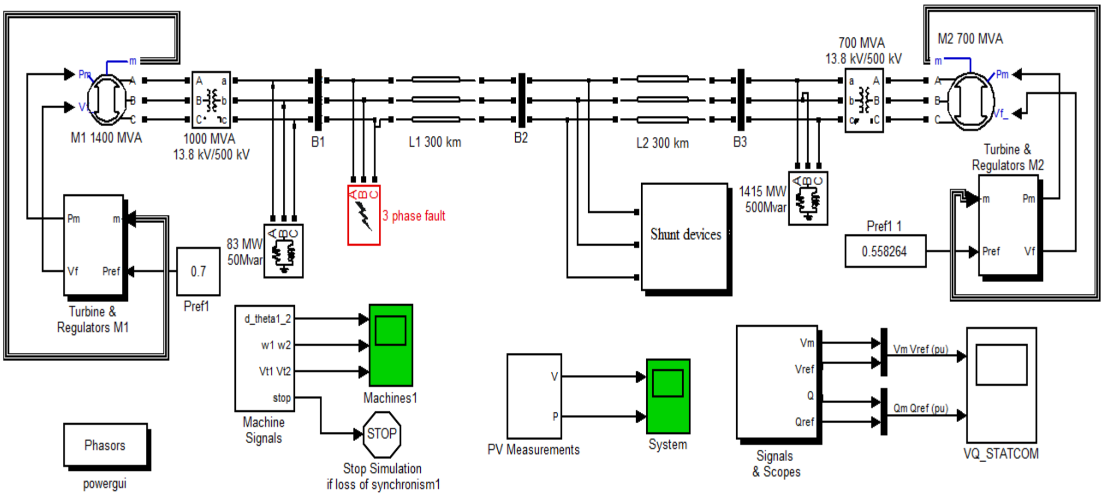


**Figure 3**: Simulation of Two-area power system with STATCOM

### 4.1 Without Controller

When a 3-ph fault [9] is occurs at the proper location in the transmission line then the system will be at out of synchronism and looses its stability.

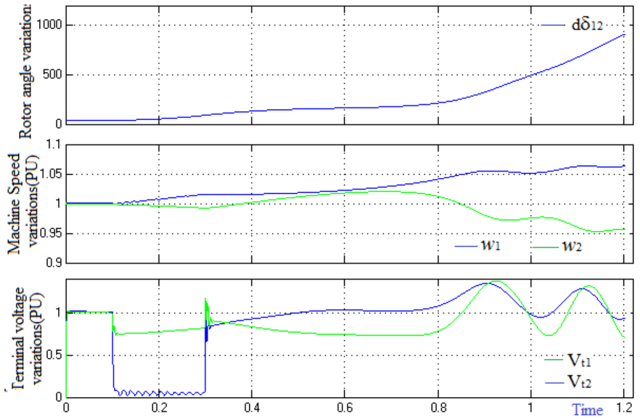


**Figure 4:** Waveforms for Rotor angle, Speed & voltages with 3-ph fault

### 4.2 With Static Var Compensator (SVC)

### a. At Midle of Transmission Line Length

On placing the SVC in the transmission line at the distance of L1=300km & L2=300km i.e. absolutely at the mid point of the transmission line,we can get the stabilised waveform at fault clearing time t=0.19 sec only.

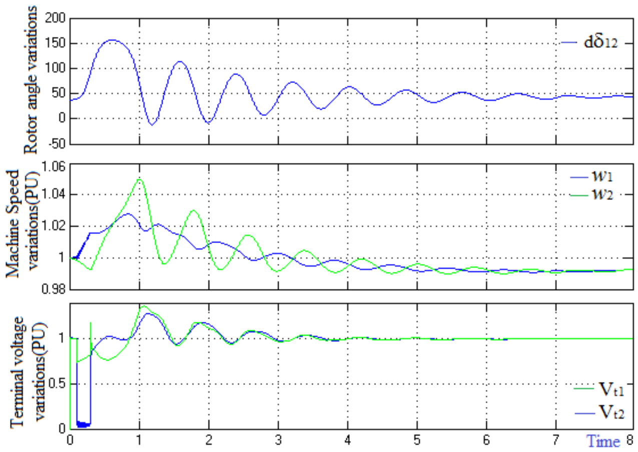
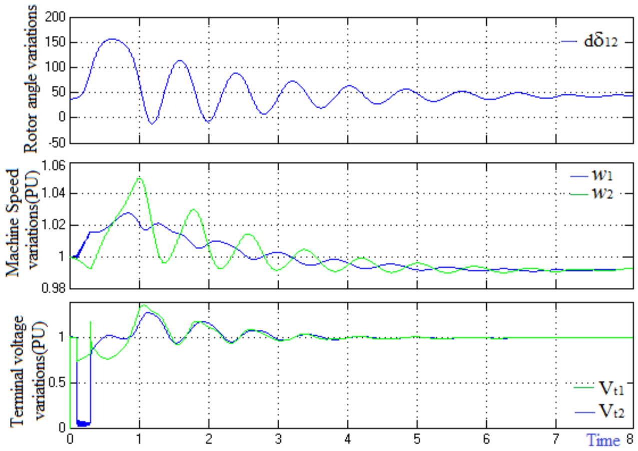


**Figure 5:** Waveforms for Rotor angle, Speed & voltages with fault by palcing SVC at middle of Transmission line

If we place the SVC in the transmission line at the distance of L1=300km & L2=300km i.e. absolutely at the mid point of the transmission line, system is unstable at FCT t = 0.2 sec

### b. Transmission line of L1=240km & L2=360km length:

On replacing the same rated SVC device at the distance of L1=240km & L2=360km, we can get the transient stability at the fault clearing time of t=0.2sec and system is in stable.



From the above analysis it is claear that the fault clearing time is >0. 2, the system never attains stability although by placing the SVC in different locations in the transmission line.

### 4.2 With Static Synchronous Compensators (STATCOM)

### a. At midle of Transmission line length:

On placing the STATCOM at the exactly at middle of Trans-mission line length distances (i.e L1=300Km & L2=300km), the system is stable with the fault clearing time of 0.2 sec.

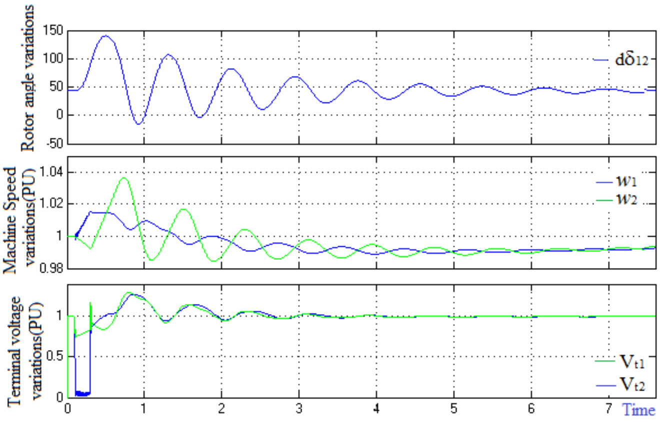


**Figure 7:** Waveform for Rotor angle, Speed & voltages with fault by palcing STATCOM at middle of Tramission line at FCT of 0.2 sec

Similarly by changing the fault clearing time in the same distances as the fault clearing time of t=0.21sec, we can't get the stabilized system.

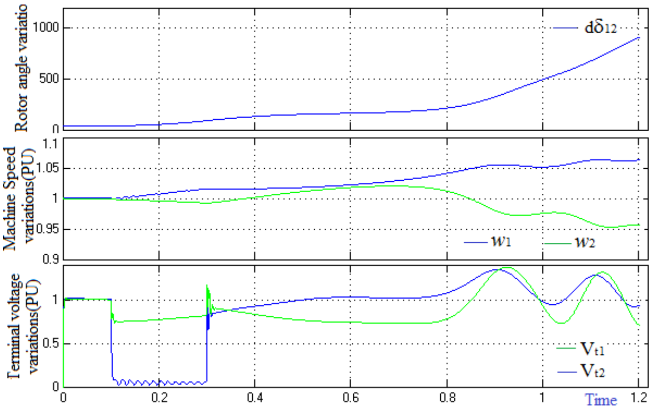


**Figure 8:** Waveform for Rotor angle, Speed & voltages with fault by palcing STATCOM at L1=300 km & L2=300km at FCT of 0.21 sec

### b. Transmission line of L1=240km & L2=360km length:

On replacing the same STATCOM device in the transmission line at the distances of L1=240 & L2=360, at the fault clearing time of t=0.21 sec we can get stable system.

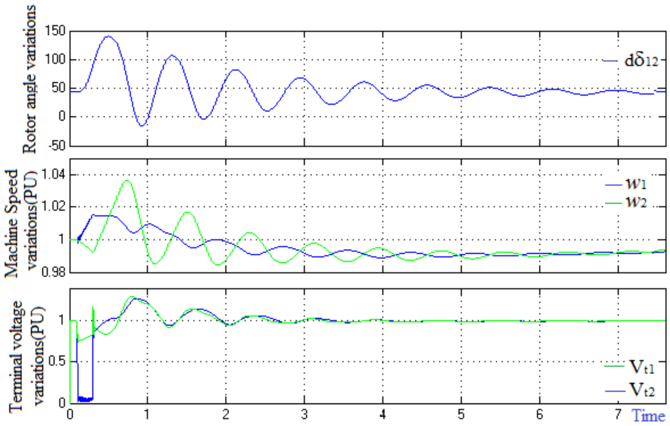


**Figure 9:** Waveform for Rotor angle, Speed & voltages with fault by palcing STATCOM at L1=240 km & L2=360km at FCT of 0.21sec

The summary of above analysis with shunt FACTS devices is expalined by the following table

**Table 1:** Comparison between SVC & STATCOM

| Length of Transmission line | With Shunt FACTS devices | |
|---|---|---|
| | SVC | STATCOM |
| L1=300KM, L2=300KM & T=0.19 sec | Stable | Stable |
| L1=300KM, L2=300KM & T=0.2sec | Unstable | Stable |
| L1=240KM, L2=360KM & T=0.2 sec | Stable | Stable |
| L1=300KM, L2=300KM & T=0.21 sec | Unstable | Unstable |
| L1=240KM, L2=360KM & T=0.21 sec | Unstable | Stable |

For a Fault Clear Time of 0.19 sec, the system is working satisfactorily when the SVC is placed at mid-point of the transmission line (for L1=300Km & L2=300Km.) But when FCT is changed to 0.2 Sec, the system loses synchronism. The same system is not losing synchronism if the location of SVC is changed slightly ( i.e when L1=240Km & L2 = 360Km) . Also the same system is sustaining its stability with STATCOM even for a FCT 0f 0.21sec. We observed STATCOM shows better performance than SVC.

## 5. Conclusion

The shunt FACTS devices (like SVC and STATCOM) are simulated for the Transient Stability Enhancement on a Two-area Power System. The system is simulated by initiating a three-phase fault near the first machine in the absence of shunt FACTS devices. In this case, the difference between the rotor angles of the two machines is increased tremendously and ultimately loses its synchronism. But, when the same fault is simulated in the presence of SVC and STATCOM, the system becomes stable. The SVC and STATCOM provides voltage support at the bus where it is connected. From the result analysis it is observed that the STATCOM shows better performance than SVC.

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