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STATE OF REGIME RELIABILITY OF ELECTRIC POWER SYSTEMS TO DEVELOP INTENSITY CONDITIONS OF NETWORKS INTERCONNECTION STRUCTURE

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Abstract- The state of regime reliability (RR) of Azerbaijan electric power system (AzEPS) under conditions of the intensity of development and action in the structure of the Power Systems Interconnection (IPS); Innovative information measurement technology SCADA/EMS-WAMS, as the main direction of modernization of the capabilities of emergency control (EC) systems; example of monitoring the state of the intersystem communication (IC) of the interconnection Azerbaijan and Georgia power systems (PS) is studied in the paper. The obligation and effectiveness of the use of the integrated SCADA/EMS-WAMS system at the AzEPS with the installation of PMU devices in the weakest nodes in order to meet the requirements of the regime reliability level in the conditions of the EPS development and its operation in the structure of the Interconnection is confirmed.

Keywords: Electric Power System, Regime Reliability, Stability, Intersystem Connections, SCADA/EMS-WAMS-PMU.

1. INTRODUCTION

AzEPS is an intensively developing EPS, operates in the structure of the interconnection of the PSs of Russian Federation (IES of the South), Georgia and Iran with the perspective of reaching the intercontinental level of the Interconnections (countries of the Middle and Near East). AzEPS has thermal and hydropower plants with large units, 500-330-220 kV power transmission lines. In terms of the network structure, it is a concentrated EPS without extended power transmission lines, but with large by power mega poles of power generation and consumption, which determines the existence of critical sections of 500-330-220 kV overhead lines (Figure 1).

In the last 20 years, along with large power plants, power plants with lower power devices (≤10 MW), as well as with the production of electricity on renewable energy sources (RES), have been developed in AzEPS. In the near future (until 2030) the RES-based electricity production may amount to about 30%, which is caused by the high resources of the RES in Azerbaijan (sun, wind, etc.).

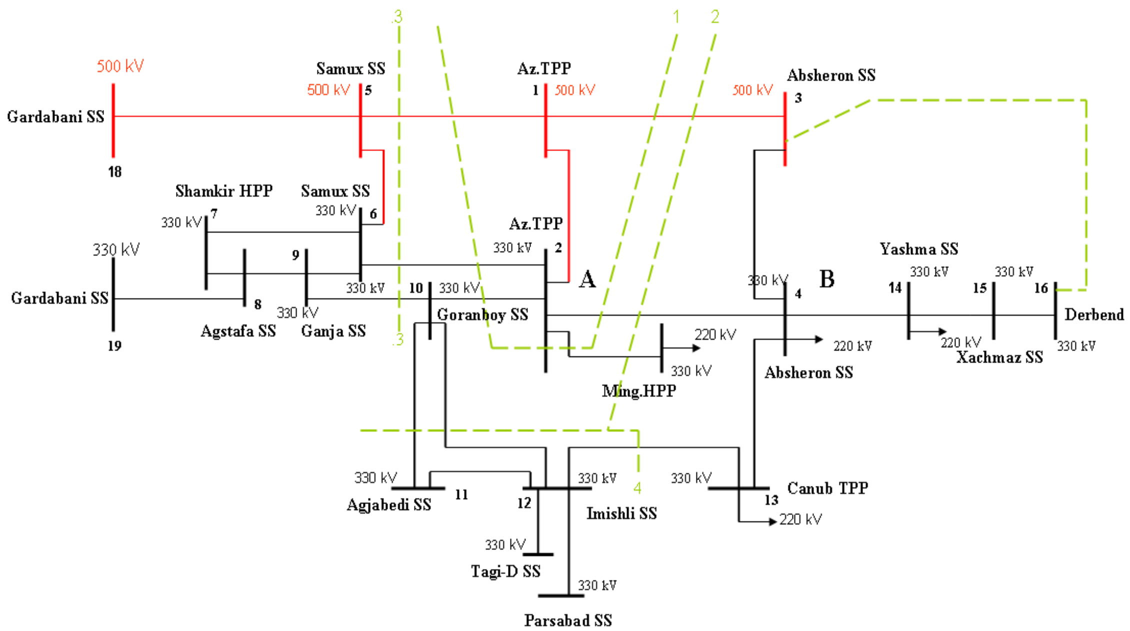

Figure 1. Transmitting part of the PS's 500-330-220 kV network with intersystem connections

At the same time, obtaining positive factors in terms of efficiency and ecological compatibility in conditions of increasing consumption of electric energy, such factors, accompanying the development, as load variability, decrement in the constant inertia of the EPS, increment in short-circuit currents complicate the work of dispatcher personnel and the working conditions of relay protection (RP) and emergency automation (EA), impact negatively on the RR of EPS. The features that determine the RR state should also include the existence in the structure of parts with power excess and deficiency, which determine the existence of critical sections of 500-330-220 kV in the system (Figure 1).

The AzEPS's operational experience, design and experimental calculations show that the instabilities in the AzEPS, as the main RR properties, can be caused due to:
- "voltage", mainly, due to emergency imbalance of reactive power;
- "current", due to equipment overload, load increments, overload of lines of sections in *n*-1, *n*-2 modes;
- "angle" at weakening of the connections with sections between the EPS parts or gradual increase in the power transfer to the part with power deficiency;
- "frequency" as a result of emergency imbalance of active power.

These disturbances can turn "one to another" type with the exit to asynchronous modes, etc. Traditionally, the solution to the problem of providing the PS stability during emergencies, as a rule, is decided by operational dispatcher (OD) and EA. Under new conditions, which are mentioned above, on the example of AzEPS, the EA can show a low failure tolerance, lack of adequacy and coordination, interaction, redundancy of initial and unprocessed information in emergency and non-standard situations.

The above mentioned increases the probability of emergency situations. World practice has enough examples of system emergencies completed with blackouts. At that, to stop the process of disintegration of the EPS by means of OD and EC is not possible [1].

2. STRUCTURE OF THE WAMS SYSTEM CONNECTİON TO THE SYSTEM

In the complex of tasks solved in order to existence the large-scale development of systemic accidents, in the early 90s of the last century, the WAMS (Wide Area Measurement System) information and measurement system was developed (USA) and implemented in many PSs, in the structure of which there are three functional components intended for monitoring (WAMS), control (WACS) and protection (WAPS) of EPS.

Problems solved using the WAMS system:
- System state assessment;
- System dynamics state assessment;
- Voltage stability assessment;
- Identification of oscillations;
- Post-emergency analysis.

Problems solved using the WACS system:
- Energy flow control;
- Reactive power control;
- System damper properties control.

Problems solved using the WAPS system:
- Generation and load balancing;
- The system partitioning;
- WACS control.

The WAMS system is based on vector (phasor) technology, which is presented in Figure 2.

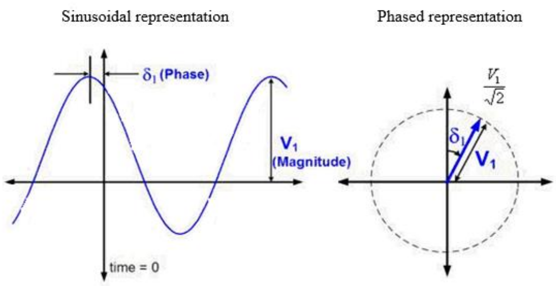

Figure 2. Vector representation of a sinusoidal signal

The main components of the WAMS system are as follows:
PMU - Phasor Measurement Unit
PDC - Phasor Data Concentrator
GPS - Global Positioning System

The PMU is the main vector of phasor technology using digital processors. Complex connection diagram and operation of the WAMS system in EPS is presented in Figure 3.

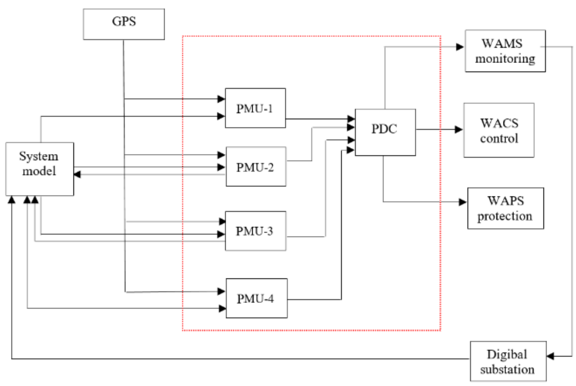

Figure 3. Structure of the WAMS system connection to the system

Receiving signals from GPS every 20 ms, PMU performs measurement in points of connection of values.

$$Y = \{U_i I_i \varphi_{ij} \delta_i\} \quad (1)$$

where, U_i,I_i are voltage and current in *i*th node of connection, φ_{ij} is the phase shift between current and voltage and δ_i is voltage phase of *i*th node.

The accuracy of the units is:
- voltage (kV) = 0.1%
- angle (°) = ±0.2%
- current (A) = ±0.2%
- current angle = ±0.2%
- frequency (Hz) = ±0.001%
- error, t = 5 μs

The information is sent to the PDC, then to the execution of the WAMS function. The complexity of processes in a complex PS that determines the regime reliability state, including electromagnetic (± ≤0.01 s), electromechanical (≤0.02 s), stationary (≤10 min), requires the integration of WAMS systems with the SCADA / EMS system, as well as the ECS (emergency control system). The latter traditionally functions in PS, it is being modernized, in particular, on the basis of microprocessor technology. SCADA/EMS is installed at a number of substations of AzEPS. An example of such integrated system is shown in Figure 4 (the problem of EPS visualization is being solved) [4].

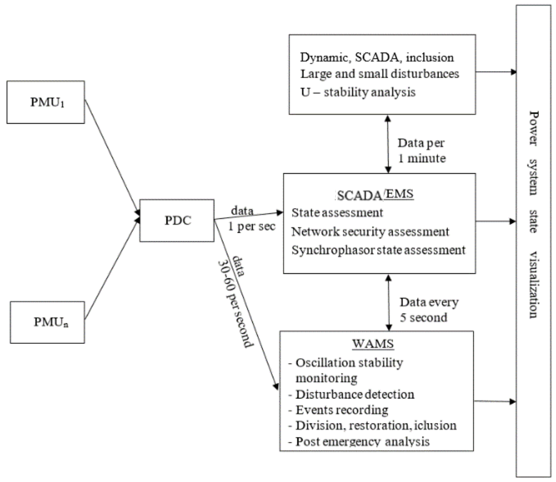

Figure 4. State visualization scheme in the integrated SCADA/EMS-WAMS system

SCADA/EMS system measures are:

$$Y = f(P_{ii} Q_{ii} P_{ij} Q_{ij} U_i) \tag{2}$$

where, P_{ii}, Q_{ii} are active and reactive powers of the *i*th generator, P_{ij}, Q_{ij} are active and reactive powers of the *i*th branch and U_i is voltage in the *i*th node

The measurement is performed on the basis of the received telemeterings (TM). Comparative data on the speed of realizing the measurement of regime parameters is presented in Table 1.

Table 1. Comparative data on the speed of realizing the measurement of regime parameters

System	System shutdown time	Event duration
WAMS	from 100 ms to 1 sec	from 100 ms to several min
SCADA	less than 5 sec	less than sec until an hour
EMS	less than 5 sec	less than min until an hour

Based on this, SCADA/EMS is used to measure in stationary modes in the ± range, WAMS and WACS-electromechanical and WAMS-electromagnetic processes. The efficiency of such integrated information system is based on the PMU technology and its optimal placement in the EPS scheme, i.e., in the "weakest" nodes and elements of the system. "Weak" are those elements, whose change of parameters to the maximum range affects the value of the PS response to a disturbance.

In the world, there is a recommendation on the advisability of installing PMU on intersystem connections, 500-330 kV SS, at the input and output of 500-330-220 kV critical sections, on the voltage buses of remote generators, the phase angle between which can affect the state of the PS stability in general, etc. [5].

3. COMPUTATIONAL AND EXPERIMENTAL STUDIES

The experience of AzEPS operation and computational and experimental studies have shown that PMUs in AzEPS should be installed at (Figure 1):

- the entrance of IC from the IPS of the South (330 kV "Yashma-Derbend"OHL), EPS of Georgia (500 kV "Samukh-Gardabani" OHL and 330 kV "Agstafa-Gardabani" OHL), PS of Iran (330 kV Imishli SS);
- on the lines of 500-330-220 kV OHL, which determine the power flow to the deficit part of the EPS;
- 220 kV "Absheron" SS, which provides the input to the deficit part of the EPS;
- a number of SG voltage buses, changes in the interphase angles of voltages in terms of speed and value are most sensitive under disturbance, etc.

Thus, in the amount of 10-11 devices in 36 nodal circuits of 500-330-220 kV, which is confirmed by design studies [6, 7, 8].

As an example, the issue of the application of PMU on IC of 500-330 kV OHL of PS of Georgia and Azerbaijan (500 kV "Samukh-Gardabani" OHL, 330 kV "Agstafa-Gardabani" OHL) is considered below (Figure 1) [9].

When controlling the modes of the IPS, one should take into account the instability of power flows through the IC, due to random load oscillations in the interconnected PSs. The level of these irregular oscillations in amplitude and frequency depends on the power of the interconnected PSs. Moreover, to the greater extent, the smaller the ratio of the limit of the transmitted power over the IC to the power of the lesser of the connected PSs (K_p). This forces us to choose the design load on IC with a large static stability margin. For weak ICs the irregular oscillations have a significant effect on the mode of operation of communications and significantly limit their carriage capacity.

According to [10], the IC is considered weak if for it the ratio of the transmitted power limit to the power of the lesser of the PSs:

- does not exceed 0.15÷1 at the power of the lesser of the interconnected PSs up to 3000 MW;
- does not exceed 0.1÷0.06 at the power of the lesser of the interconnected PSs up to 3000÷10000 MW;
- does not exceed 0.08÷0.05 at the power of the lesser of the interconnected PSs up to 10000÷30000 MW;
- does not exceed 0.05÷0.03 at the power of the lesser of the interconnected PSs up to 30000÷60000 MW.

Due to the features that modern PSs have, the irregular oscillations can be significant and continual. Therefore, in order to maintain a given level of exchange power and prevent overloads dangerous for stability, the control must be carried out continuously in real time.

Communications between the PSs of Georgia and Azerbaijan are carried out via the 2nd IC (Figure 1).

- 500 kV "Samukh-Gardabani" overhead line,
- 330 kV "Agstafa-Gardabani" overhead line.

The considered mode and scheme are characterized by the following data:

Azerbaijan PS: $P_G = 4447$ MW $P_N = 3219$ MW
Georgia PS: $P_G = 2349$ MW $P_N = 2905$ MW

Table 2. The results of calculation of the carrying on IC

	Power flow on 500 KV "Gardabani-Samukh" OHL, MW	Total power over two lines, MW	δ_1, degree	δ_2, degree	δ_1-δ_2, degree
Initial mode	349	602	-10.7	-5.1	-5.6
Heavy conditions					
1	412	713	-13	-6.3	-6.7
2	448	778	-14	-6.6	-7.4
3	499	876	-14.6	-6.3	-8.3
Limit conditions	537	943	-16.2	-7.1	-9.1

Flows along ICs:
500 kV "Samukh-Gardabani" overhead line - 350 MW,
330 kV "Agstafa-Gardabani" overhead line - 250 MW.

The results of calculation of the carrying on IC are shown in Table 2.

Based on which for the above value of K_p we will have: at operation of two lines

$$K_p = \frac{943}{2349} = 0.403 \tag{3}$$

at operation of one 500 kV "Samukh-Gardabani" OHL

$$K_p = \frac{537}{2340} = 0.229 \tag{4}$$

The obtained values of K_p>0.15-1.0, which refers the indicated IC to "weak" ones. Nevertheless, to maintain the power flow through the IC at the proper level, i.e. with a normative static stability margin, the generating and loading power of the IPS should be controlled: to reduce the power flow through the IC, the generation power in the transmitting Azerbaijan PS and load reduction in the receiving Georgian PS should be limited.

The actual level of unloading depends both on the power ratio and on the steepness coefficients of the static frequency characteristics of the interconnected PSs, determined by the relationship [11]:

$$K_c = \frac{\Delta P}{\Delta f} \cdot \frac{f_o}{P} \tag{5}$$

f_o - rated frequency (50 Hz),
P - load power (MW),
ΔP - power increment on IC (MW),
Δf - steady-state frequency change (Hz).

With the decrease in generation in the Azerbaijan PS by 560 MW, the frequency is set to f = 49.23 Hz (Figure 5). Then,

$$K_c = \frac{560 \times 50}{0.77 \times 6124} = 5.93 \tag{6}$$

The K_c value is defined by the amount of power injection required to restore the f frequency. The $\Delta f(\Delta P)$ characteristics can be used to form the control actions based on the results of PMU readings. Figures 5 and 6 show Such characteristics (obtained by calculation) at generation reset in the Azerbaijan PS and load disconnection in the Georgian PS are shown in Figures 5 and 6, respectively.

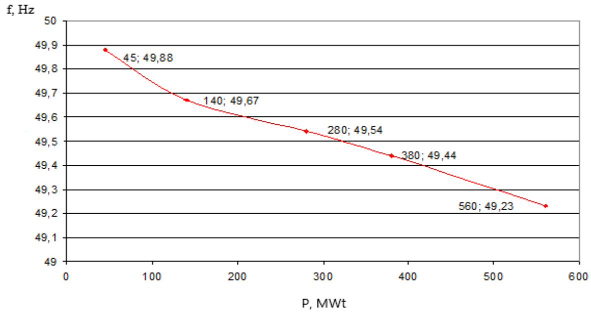

Figure 5. Frequency response at generation rejection in Azerbaijan PS

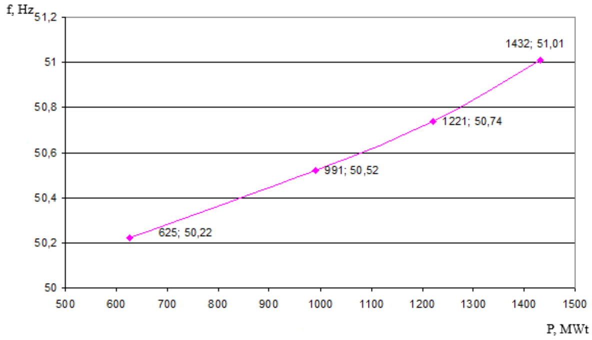

Figure 6. Frequency response at disconnection of part of the load in the Georgian PS

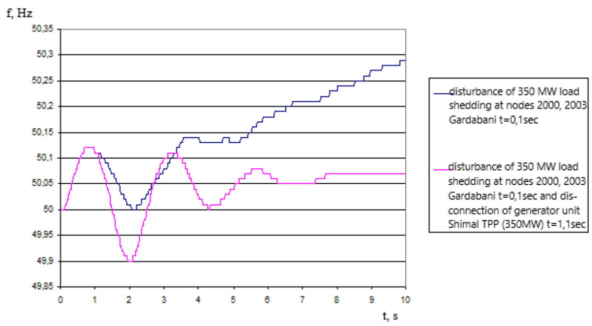

Figure 7. f-recovery at load shedding in the Georgian PS when using PMU data according to the $\Delta P/\Delta f$ characteristic

When measuring the frequency (PMU), monitoring it (WAMS) and detecting its deviation from the standardized value, the control (WACS) is applied to restore it by affecting the power balance. So, at 350 MW load shedding at the Gardabani node at t = 0.1 s at approximately f = 50.12 Hz, in 1 s a signal for the SG of Shimal TPP disconnection may follow and the frequency is restored to 50.07 Hz (Figure 7).

The PMU device by measuring the voltage phase difference at the ends of the IC can provide the ability to control the IC's carrying capacity. The plotted characteristic allowing for the controlling the IC's carrying capacity of the 500 kV "Samukh-Gardabani" OHL according to the PMU measuring the voltage phase difference on the IC is presented in Figure 8. According to this characteristic, the transmitted power limit through the considered communication is 537 MW and can be achieved at voltage phase difference on IC of 9.1°.

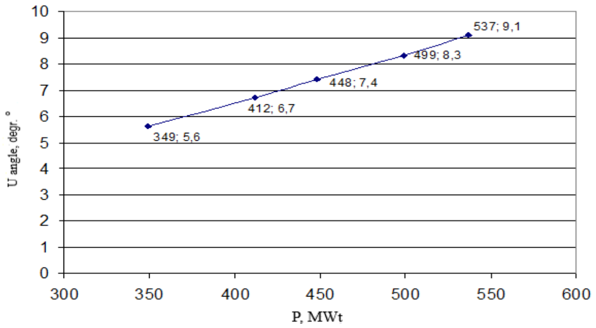

Figure 8. "Change in the voltage phase difference - the transmitted power along the 500 kV Samukh-Gardabani OHL" relationship

The Figures 5, 6 and 8 shows the capabilities of the system (WAMS) connected to the IC in terms of monitoring and control of static stability.

In dynamic modes the determining factor for assessing stability is the change in the relative angles of the rotors of the generators of interconnected PSs.

The Figures 9, 10 and 11 show the dynamics of changes in the relative rotor angles and voltages of the SG of AzTPP and Inguri at 3-phase short circuit at the 500 kV "Samukh" SS are shown in Figures 9, 10 and 11. At automatic reclosing t = 0.12 s, the stability is preserved (Figure 9). It is maintained up to t = 0.52 s (Figure 10), although the relative angle sharply increases. At t = 0.56 s, the stability is disturbed (Figure 11).

The PMU, connected to the "Samukh-Gardabani" IC, can give a signal to control actions a little earlier.

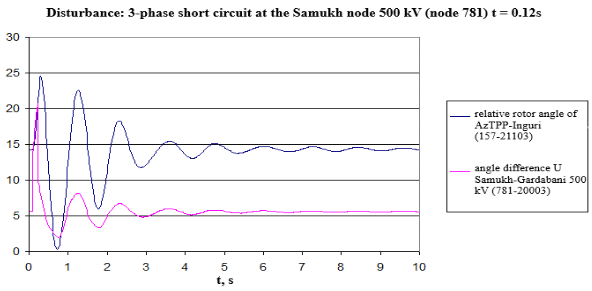

Figure 9. Comparison of the dynamics of change in the mutual angles of the rotors of the "AzTPP-Inguri" SG and the voltage phase difference on IC of the 500 kV "Samukh-Gardabani" overhead line (t, s)

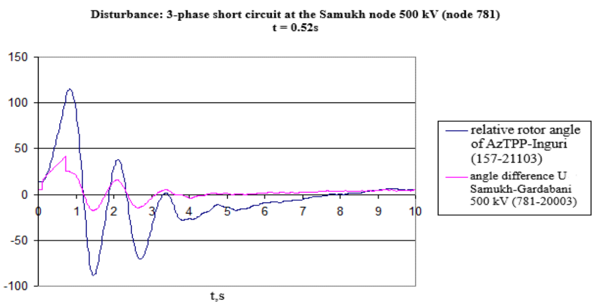

Figure 10. Comparison of the dynamics of change in the mutual angles of the rotors of the "AzTPP-Inguri" SG and the voltage phase difference on IC of the 500 kV "Samukh-Gardabani" overhead line

The analysis, the results of which are selectively presented above (Figures 5-11), indicates the advisability of switching on the PMU at the 500 kV "Samukh" SS, as well as at the 330 kV "Akstafa" SS, which will allow for monitoring and controlling of static and dynamic stability of PS by the WAMS system according to the results of measurements of the frequency and voltage phase difference.

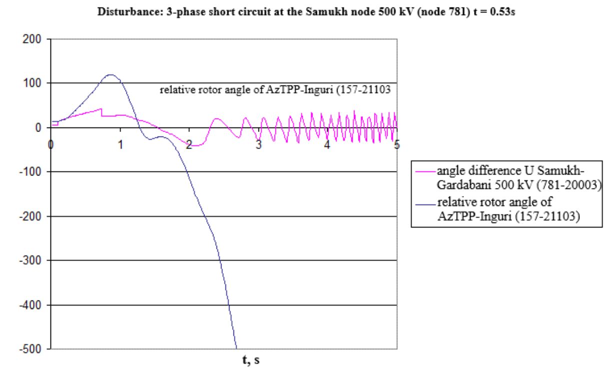

Figure 11. Comparison of the dynamics of change in the mutual angles of the rotors of the "AzTPP-Inguri" SG and the voltage phase difference on IC of the 500 kV "Samukh-Gardabani" overhead line

4. CONCLUSION

The importance and effectiveness of the usage of the integrated SCADA / EMS-WAMS system at the AzEPS with the installation off PMU devices in the weakest nodes in order to meet the requirements for the regime reliability level in the conditions of the EPS development and its operation in the structure of the Interconnection is confirmed.

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BIOGRAPHY

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