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Monitoring for Mutual Effects of Switching Power Capacitors in Power Systems

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ABSTRACT

Power system perturbations are due to many reasons; one of the most common perturbation causes is switching off/on the power capacitors. This paper monitors and discusses the overvoltages which appear on local and remote capacitor connected buses in power systems. Using the Fast Fourier Transfer (FFT), the total harmonic content of voltages and currents waveforms is also estimated at all buses. The power factor during different cases of switching modes "off/on" is monitored. The monitoring technique tackles not only the longitudinal long distance mutual effects of switching power capacitors between different buses but also evaluates the overvoltage durations. A relative long term monitoring is implemented using the Matlab/Simulink environment to show severity assessments in different switching modes on the transformers' voltages and currents' waveforms.

Keywords: Overvoltages and currents monitoring- Switching power capacitors – Switching power capacitors mutually effects

1. Introduction

Distribution power systems' loads have the characteristic of absorption of reactive power due to their inductance. This will result in lowering the entire system power factor. Therefore, it is necessary to have a larger reactive power compensator to reduce the inductance effects[1]. Power quality overvoltage conditions in a power system may be either at system frequency or due to transient surges with higher frequency components. Theses types can be summarized as follows [2]:

1. Under steady state conditions the system frequency voltage may exceed the rated voltage in some parts of the system.
2. Transient or dynamic type overvoltages may be either internally generated or externally imposed.
3. Overvoltages due to lightning strokes.
4. Switching surges overvoltages (and other dynamic power quality problems).

The increased application of shunt capacitor banks in power systems, along with the increased use of power factor correction capacitors at industrial installations, has resulted in switching transient overvoltages causing some

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disturbances to customers' sensitive electronic equipment [3-5].

Fig. 1 represents a substation of 33/11 kV fed from a grid station 220/33 kV through two 80 MVA transformers.

A double circuit 30 Km transmission line 33KV connects the substation under consideration to the grid station. The 33 KV bus is connected to a substation through a very long transmission line 90 Km 33 KV to feed a load of about 1 MW. The load on the 11KV bus is about 12 MW with a power factor variable between 0.65 and 0.8. Fig. 2 shows the results obtained for the voltages at both the 33KV bus and 11 KV bus of the considered substation at full load for the switching off of a capacitor bank unit of 2MVA out of 4MVA at t=0.065 sec. It is clear that switching the bank capacitors off will lead to overvoltages on both the 11 KV and the 33 KV busses. The condition will be more severe in the case of switching off the same amount of capacitor banks under light load conditions [6].

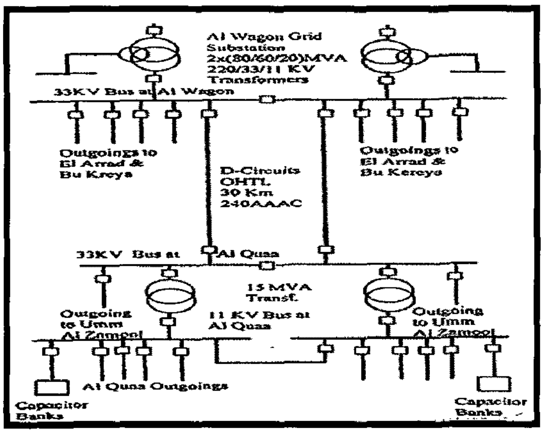

Fig. 1 Single line diagram for 230/33/11 kV substation

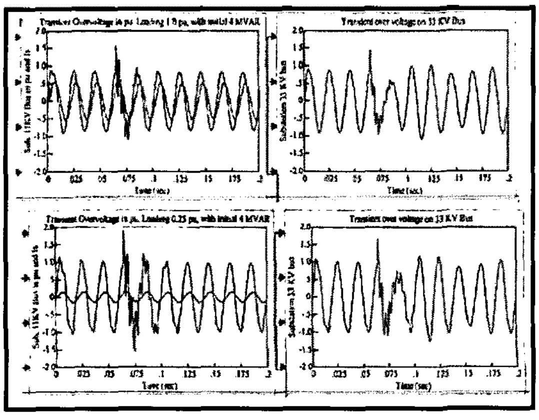

Fig. 2 Transient Over voltage in pu for 33 kV and 11 kV sides at different loads with switching off 4 MVAR bank capacitors

The effects and determination of the relative locations of the switched capacitor bank are considered in [7]. Fig. 3 shows the considered one-line diagram where a capacitor bank is energized. A power-quality monitoring device (PQM) is located on both sides of the capacitor bank with its current-transformer (CT) direction pointing in the direction of the feeder current. Therefore, in this arrangement, the switched capacitor bank is physically down line from PQM 1, but up line from PQM 2. Fig. 4 shows the voltage and current waveforms measured at PQM 1 and 2.

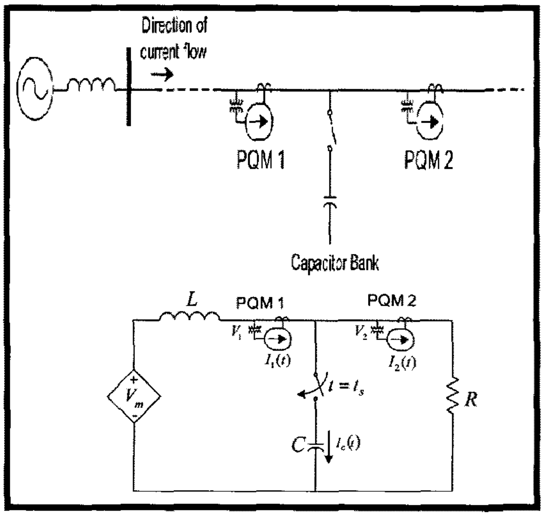

Fig. 3 Switched capacitor bank is down line from the power-quality monitor (PQM) 1 and up line from PQM 2.

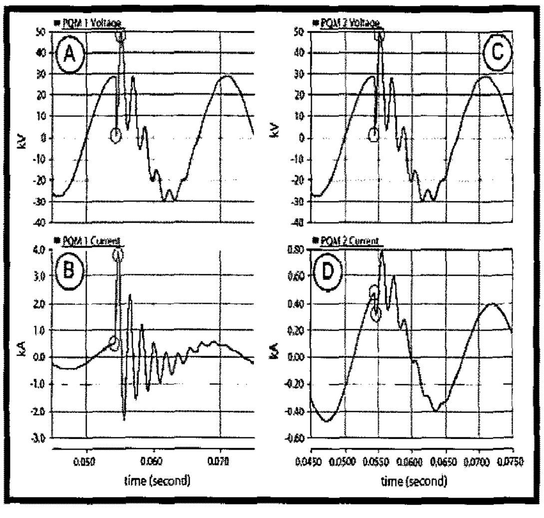

Fig. 4 Voltage and current waveforms recorded from PQMs: PQM 1 (A and B), and PQM 2 (C and D). Note that current (vertical) axes on B and D are dissimilar

2. System Under Study

Fig. 5 presents a single line diagram to investigate the current system. Table 1, Table 2 and Table 3 present the different parameters of the loads, transformers and transmission lines, respectively.

Table 1 The different load parameters

Load No.	MVA	KV	P(MW)	Q(MVAR)	
				Qxl	Qxc
1	3	69	2.1	2.36	0.236
2	1.5	0.48	1.05	1.178	0.1178
3	1.725	4.16	1.2075	1.355	0.1355
4	1.25	4.6	0.875	0.982	0.0982
5	1.5	0.48	1.05	1.1783	0.11783
6	1	0.48	0.7	0.7855	0.07855
7	0.5	0.48	0.35	0.3927	0.03927
8	2	2.4	1.4	1.5711	0.15711
9	1.75	2.4	1.225	1.375	0.13745

Table 2 The different distribution line parameters

Line No.	R1 (ohm/km)	R0 (ohm/km)	L(μH /km)	C(pF/km)
1	0.00265	0.0795	16.3	1.18
2	0.00232	0.0696	13.4	0.97
3	0.00208	0.084	4.9	0.358
4	0.00299	0.0879	7.1	0.518
5	0.00143	0.0429	3.4	0.2482

Table 3 The different transformer parameters

Trans. No.	MVA	KV	R1 (ohm)	L1(H)	R2 (ohm)	L2(ohm)
1	200	230/69	2.52	14.9	0.0092	0.0539
2	100	69/13.8	0.46	2.69	0.0183	0.108
3	3.75	13.8/4.16	0.49	2.87	0.0147	0.0871
4	1.5	13.8/4.6	1.22	7.19	0.00147	0.0087
5	30.5	13.8/0.48	0.061	0.353	7.2E-5	4.2 E-4
6	30.25	13.8/0.48	0.061	0.356	7.3E-5	4.3E-4
7	30.725	13.8/2.4	0.059	0.3514	5.4 E-3	3.1E-2
8	1.5	13.8/0.48	1.22	7.19	14.E-4	8.7E-3

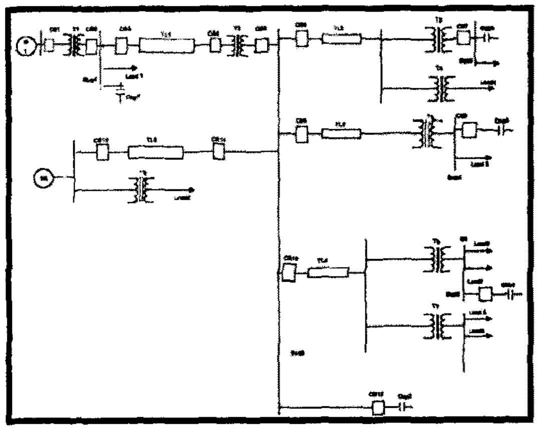

Fig. 5 The single line diagram for the considered power system

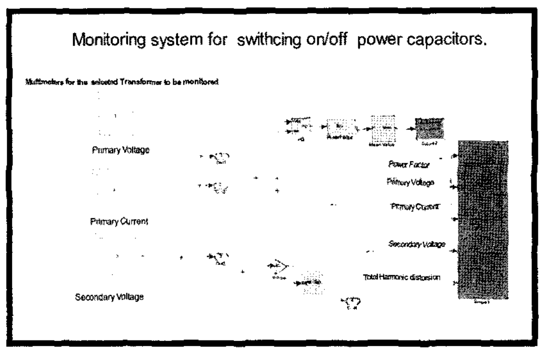

Fig. 6 The proposed monitoring model for the considered system under study

3. Studied Cases and Results

To monitor the effects of switching the different capacitors at their local or remote buses, a suitable capacitor value of MVAR is adjusted to achieve the change of the power factor from 0.7 to 0.9 according to the actual local buses power components (active and reactive power). The different capacitors' values that are connected to the different buses are presented in Table 4.

Table 4 The different values of the different considered capacitors

Capacitor No.	Cap.1	Cap.2	Cap.3	Cap.4	Cap.5
MVAR	1	2	0.33	0.33	0.33

The different scenarios for switching the different capacitors and monitoring their effects over the voltages and current regarding their peak values, total harmonic

Table 5 The different switching scenarios and their effects over the voltages and currents waveforms (Bus 1 &2)

Cap. No.	Bus 1						Bus 2					
	Voltage			Current			Voltage			Current		
	P.U	THD %	Cycles	P.U	THD %	Cycles	P.U	THD %	Cycles	P.U	THD %	Cycles
Cap.1	1.996	0.51	1.5	1.010	2.78	0.25	2.679	0.5	1.5	0.982	2.78	0.25
Cap.2	1.060	0.37	2	1.010	63.30	4	1.893	9.15	4	3.028	63.36	4
Cap.3	1.066	0.01	1	1.003	2.75	1	1.977	0.04	1	1.017	2.87	1
Cap.4	1.03	0.01	0.5	1.00	3.80	0.5	1.641	0.04	0.5	1.0	3.80	0.5
Cap.5	1.03	0.01	0.5	1.0	3.74	0.5	1.641	0.04	0.5	1.0	3.74	0.5

Table 6 The different switching scenarios and their effects over the voltages and currents waveforms (Bus 3&4)

Cap. No.	Bus 3						Bus 4					
	Voltage			Current			Voltage			Current		
	P.U	THD %	Cycles	P.U	THD %	Cycles	P.U	THD %	Cycles	P.U	THD %	Cycles
Cap.1	2.759	0.50	1.5	0.973	3.75	0.25	2.517	0.73	1.5	1.049	3.17	0.25
Cap.2	1.902	9.15	4	1.465	3.75	4	1.770	8.16	4	1.274	3.72	4
Cap.3	1.902	0.04	1	3.668	3.70	1	2.553	0.64	1.5	1.070	3.71	1.5
Cap.4	1.813	0.04	1.5	1.129	4.18	1.5	2.050	8.70	2.5	1.535	9.95	2.5
Cap.5	1.813	0.06	2	1.246	12.46	2	2.050	0.64	0.5	1.070	3.71	0.5

Table 7 The different switching scenarios and their effects over the voltages and currents waveforms (Bus 5)

Cap. No.	Bus 5					
	Voltage			Current		
	P.U	THD %	Cycles	P.U	THD %	Cycles
Cap.1	2.684	0.55	1.5	1.026	2.29	0.25
Cap.2	1.685	8.65	4	1.131	3.78	4
Cap.3	2.705	0.33	2	1.048	3.78	1
Cap.4	2.237	0.34	0.25	1.048	3.78	0.5
Cap.5	2.237	19.20	3.5	1.956	38.11	3.5

distortion and the numbers of the cycles that the distortion remains are presented in Table 5, Table 6 and Table 7. It can be noticed that the local effects of switching a capacitor which is connected to the local bus are much higher than the mutual effects for the remote bus.

Fig.7 shows the different monitored quantities at bus bar No. 4 when switching its local capacitor number 4. It can be noted that the power factor is improved from 0.7 to 0.9 due to injecting the capacitor. Meanwhile, the overvoltage built on the secondary winding reaches almost double the rated value and the secondary current reaches a very high value of 6.3 kA. The primary voltage is almost the same because of the filtering effects of the transformer inductance. So, to improve the power factor, the effects of the overvoltage built up on the transformer winding and the resulting reduction of its lifetime should be considered an asset management issue.

Fig. 8 shows the different monitored quantities at bus bar No. 1 when switching its local capacitor number 1. The power factor remains almost the same due to its connection at the source location. Meanwhile, the overvoltage built up on the secondary winding reaches almost double the rated value and the secondary current reaches a very high value of 3.4 kA. The primary voltage reaches double the value due to the absence of the transmission system inductance and the low value of transformer No. 1 inductance.

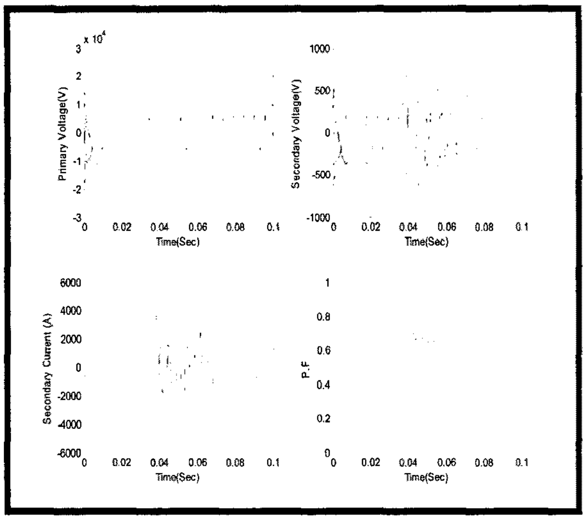

Fig. 7 The developed model's results for the case of switching the Capacitor No. 4

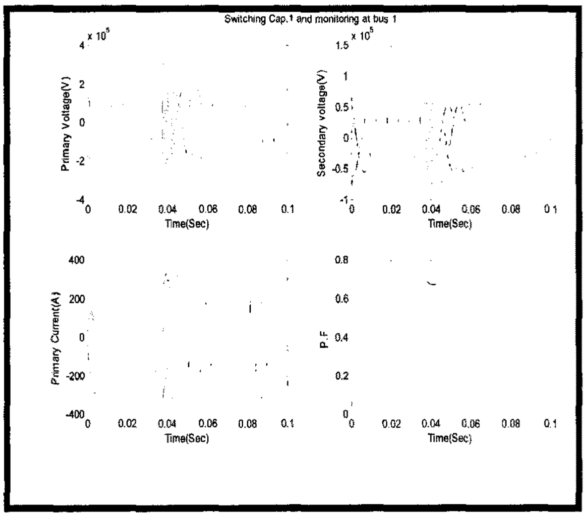

Fig. 8 Presents the developed model's results for the case of switching the Capacitor No. 1

Fig. 9 shows the different monitored quantities at bus bar No. 5 when switching remote capacitor number 1. The power factor remains almost the same due to its connection at the source location. Meanwhile, the overvoltage built on the secondary winding reaches almost double the rated value, the secondary current is almost the same because of the high value of the system inductance between the source and the monitored bus bar No. 5, and the primary voltage reaches double the value.

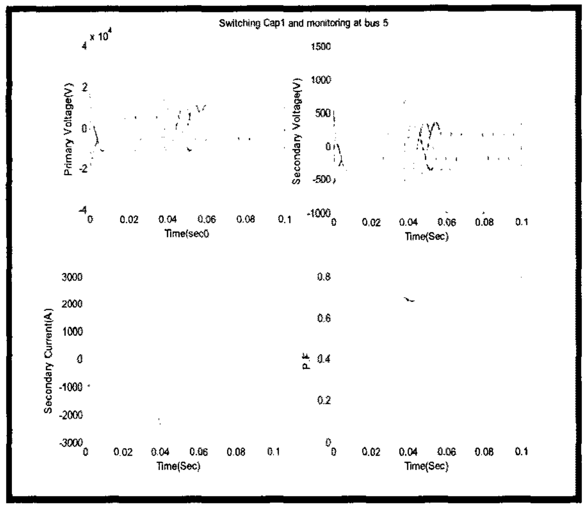

Fig. 9 Presents the developed model's results for the case of switching the Capacitor No. 1 and monitoring at Bus bar 5

Fig. 10 shows the different monitored quantities at bus bar No. 1 for the case of switching remote capacitor number 5. The power factor remains almost the same due to monitoring on the source location. Meanwhile, the overvoltage and the overcurrent built on the secondary winding become almost negligible because of the high value of the system inductance between the source and the switched capacitor No. 5.

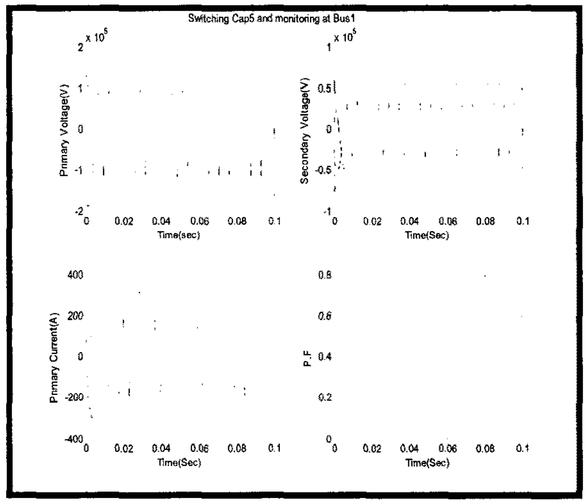

Fig. 10 Presents the developed model's results for the case of switching the Capacitor No. 5 and monitoring at bus bar No. 1

Fig. 11 shows the different monitored quantities at bus bar No. 5 for the case of switching on/off its local capacitor number 5. The power factor which remains is improved from 0.7 to 0.9 when the capacitor is switched on and it comes down again to its initial value of 0.7 when the capacitor is switched off. Meanwhile, the overvoltage and the overcurrent built on the secondary winding reaches almost double during the switching periods and the primary voltage is almost the same due to the high value of transformer No. 5 inductance.

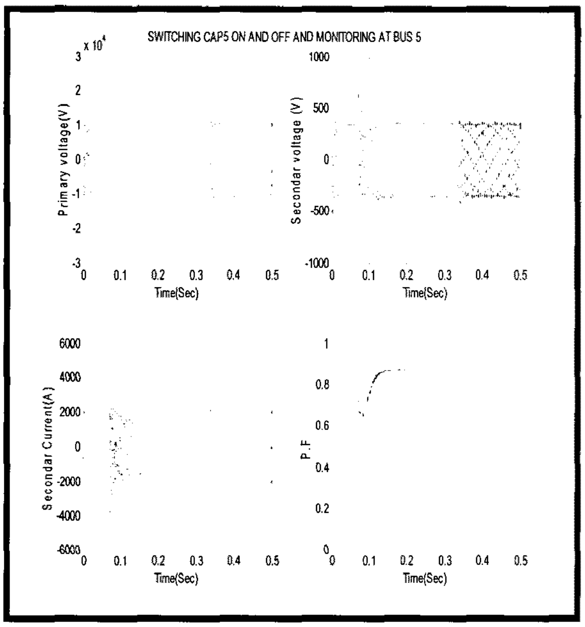

Fig. 11 Presents the developed model's results for the case of switching on/off the Capacitors No.5 and monitoring at bus bar No. 5

Table 8 presents the voltage and current parameters for the case of switching two capacitors at the same time. The two capacitors No. 4 and No. 5 are switched on at the same time and monitored at their local buses. The overvoltage at bus bar No. 4 is reduced by about 10% when switching Cap. No. 4 only but the THD is increased by almost 200% and the number of cycles is increased by almost two cycles. The current is increased by almost 40%.

The over voltage at bus bar No. 5 is reduced by almost 40% when switching Cap. No. 5 only but the THD is increased by almost 20% and the number of cycles is increased by almost two cycles. The current is increased by almost 5%.

Table 8 The voltage and current parameters on the primary side of transformers No.4 and No.5 for switching the two capacitors Cap.4 and Cap.5 at the same time

Voltage Parameters				Current Parameters			
Bus No.	P.U	THD	Cycles	Bus No.	P.U	THD	Cycles
Bus4	1.91	22.20%	>4	Bus4	1.8	3.97%	>4
Bus5	1.8	21.95%	>4	Bus5	1.95	25.36%	>4

Fig. 12 shows the per unit voltage for the mutual effects of switching each capacitor on the different bus bars. It is evident that the local effects of switching the local bus bar appear greater than the remote effects.

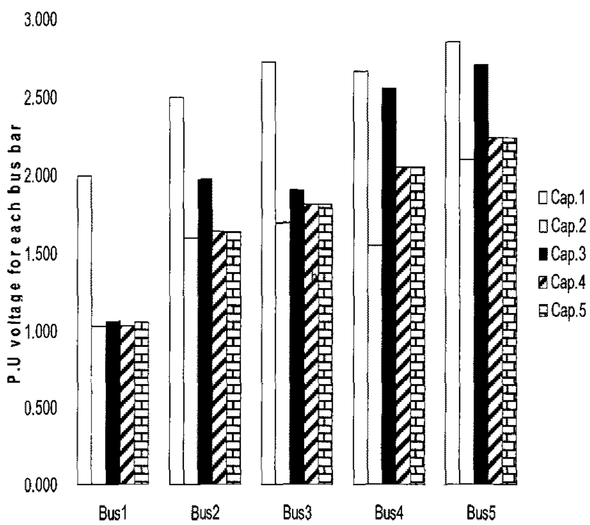

Fig. 12 The developed model's results for the case of switching the Capacitor No. 5

4. Conclusion

The effects on the local and the remote bus voltages due to switching on/off of the power capacitors are investigated. Not only the power factor improvement, but also the mutual effects of switching on/off over the different buses are captured. The total Harmonic distortion (THD) using a fast Fourier Transfer (FFT) is calculated. Based on the developed model and study the following items can be concluded:

The effect of switching on power capacitors to improve the power factor is more limited at the local bus than the remote buses.

The overvoltage appears when switching on the power capacitor at load side for the local bus and closest buses and its effects on the source bus can be neglected. Meanwhile, switching on the power capacitors on the source side causes overvoltages on both the load and source buses.

Switching two power capacitors at the same time reduces the over voltages but it increases the total harmonic distortion and the No. of cycles.

Deep investigation of the overvoltage built up across the transformer windings will yield a very good analysis for asset management to evaluate the reduction in lifetime caused by switching power capacitors.

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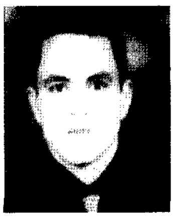

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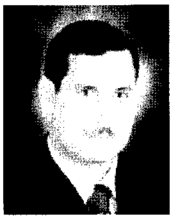

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