International Journal on
"Technical and Physical Problems of Engineering"
(IJTPE)
Published by International Organization of IOTPE

ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com

June 2015	Issue 23	Volume 7	Number 2	Pages 90-95

RECONFIGURATION OF A DISTRIBUTION NETWORK IN A RESTRUCTURED POWER INDUSTRY FOR MINIMIZING THE COST OF ENERGY LOSS

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Abstract- This paper presents a model for reconfiguration of distribution system regarding requirements of Distribution Companies (Discos) in Iran. The objective function is minimizing the cost of energy losses regarding market prices and the load patterns. Moreover, tap setting of sub-transmission transformers are done along with reconfiguration. The model is solved by Genetic Algorithm (GA) and also evaluated by executing on 33-bus test system and a practical system in Iran considering different scenarios. In all cases, the results show the effectiveness of procedure and validate presented model.

Keywords: Reconfiguration, Distribution Network, Energy Loss, Energy Price, Load Pattern.

I. INTRODUCTION

One of the main concerns of Distribution System Operator (DSO) is the optimal operation of the network, in which the system losses are minimized and all equipment are operated in the permitted limits. The distribution networks commonly have radial structure, and are operated at medium and low voltage levels, for which the currents are relatively high and accordingly the corresponding line losses are high too. According to the report of ministry of energy, the total loss of distribution network in Iran has been 14.7% in 2012, while for Khuzestan province the loss has been 22.67% [1].

This is due to the environmental condition of Khuzestan for which the air temperature reaches to 52 degree centigrade in summer and the electrical consumption increased significantly when the cooling equipment are used by the consumers. The total load curve of Khuzestan in summer days has two peaks, the first is during hours 13-16 and the second one is during hours 21-24. Moreover, the summer peak is almost 3.5-4 times of winter peak. Considering this situation, the energy losses are very high especially in summer season and reducing the system loss is an important work.

To manage and reduce the losses of distribution network, extensive researches are done regarding different strategies, including capacitor placement [2], applying Distributed Generator (DG) [3, 4], DSTATCOM Planning [5], Distribution System Reconfiguration (DSR) [6-16] and etc. Since the last one uses no additional components, is more attractive economically.

DSR is altering the network topology by changing the status of sectionalizing and tie switches to improve the network operation, while keeping the radial structure of the network. Due to distribution system infrastructure, and distribution company policies, DSR may be performed seasonally, monthly, weekly, or even daily in more automated distribution systems [6, 7]. Since distribution systems in Iran are no automated, this paper concentrated on seasonal reconfiguration of distribution systems.

A literature review indicates that in most of the researches, power losses minimization is considered as the main objective of DSR problem [8-10]. Besides, additional objectives such as load balancing [11], security and reliability enhancement [12, 13] and voltage improvement [14] have been taken into consideration. The common constraints of the problem are permitted voltage limits of all nodes, permitted power limits of all lines, keeping the radial structure of the network and feed all loads. Although many researchers are focused on power loss reduction as the main objective, however, energy loss reduction is more important in the restructured power system in which the economic aspects are significant for all market players such as Discos. In this respect, a few authors are deal with energy loss reduction of distribution systems.

The authors of [15] present an algorithm for distribution system reconfiguration and capacitor placement for energy loss reduction. The energy loss is calculated based on the energy price and daily load patterns. The load curves and energy price are supposed to be constant for a two-year planning horizon. In [16] an algorithm for both distribution system reconfiguration and capacitor placement is presented for which three load levels are considered to calculate the energy losses. All loads are supposed to be simultaneously at 0.5 pu, 1 pu or 1.8 pu, and a constant energy price is considered for all load levels. In a restructured power industry, Disco purchases energy from wholesale market in hourly prices, which have a significant effect on the best configuration of the system. Therefore, the energy price should be properly taken into account.

This paper presents a model for minimizing the cost of energy loss of distribution network via reconfiguration taking into account the requirements of DISCCOS in Iran, focusing on Khuzestan province. The market prices and the load patterns are observed the same as practical systems in Iran, Khuzestan. Moreover, based on the operational roles in Khuzestan Electric Power Distribution Company (KEPDC), tap of sub-transmission transformers are set seasonally. If tap setting and system reconfiguration are performed separately, the system will go away the best solution. Therefore, in this paper, the tap setting is done along with reconfiguration. GA is used to solve the problem. The rest of the paper is organized as follows: section II presents the problem formulation and solving. Numerical results are provided in section III, and the paper is concluded by section IV.

II. PROBLEM FORMULATION

The load curve of different types of consumers including residential, commercial, and administrative and teaching center, and also the hourly market prices are assumed to be given. The wholesale energy market in Iran is settled in a pay as bid auction for GENCOS, while Discos pay the weighted average of GENCO prices. Each Disco faced by the same hourly prices at all connection points with transmission system. Accordingly, the presented model can be formulated as follows:

A. Objective Function

$$\text{minimize: } \sum_{t=1}^{24} \mu(t) \sum_{i=1}^{N_l} R_i I_i^2(t) \tag{1}$$

where, $\mu(t)$ is the market price at hour t, N_l is number of branches.

B. Constraints

1- Power flow equations:

$$P_i = \sum_{j=1}^{N_b} \left|Y_{ij} V_i V_j\right| \cos\left(\theta_{ij} + \delta_j - \delta_{ji}\right) \tag{2}$$

$$Q_i = -\sum_{j=1}^{N_b} \left|Y_{ij} V_i V_j\right| \sin\left(\theta_{ij} + \delta_j - \delta_{ji}\right) \tag{3}$$

where, N_b is number of buses, $Y_{ij} = |Y_{ij}| \angle \theta_{ij}$ is component (i, j) of nodal admittance matrix, $V_i = |V_i| \angle \delta_i$ is voltage of node i.

2- Steady-state security constraints of distribution networks:

$$V_{i,\min} \le |V_i(t)| \le V_{i,\max} \quad \forall t = 1:24 \tag{4}$$

$$|S_{ij}(t)| \le S_{ij,\max} \quad \forall t = 1:24 \;\; \forall i, j = 1: N_b \tag{5}$$

where, $V_{i,\min}$, $V_{i,\max}$ are lower and upper limits of voltage magnitude at node i, S_{ij} is the power passed through the branch connected between node i and node j, $S_{ij,\max}$ is the capacity of line connected between node i and node j.

3- The capacity constraint of sub-transmission transformers:

$$E_i(t) \le S_i^{\max} \quad \forall t = 1:24 \tag{6}$$

where, $E_i(t)$ is power passed through the sub-transmission transformer i, $S_i^{\max}$ is the capacity of sub transmission transformer i.

4- The transformer tap constraint:

$$-T_i^{\max} \le TS_i \le T_i^{\max} \tag{7}$$

where, $T_i^{\max}$ is the half of number of tap steps of transformer i regardless neutral tap, TS_i is the tap setting of transformer i.

5- Keeping the radial structure of the distribution network:

$$N_l = N_b - 1 \tag{8}$$

$$P_{ij} \le 1 \quad \forall i, j \in S_{bus} \tag{9}$$

where, P_{ij} is number of paths exists between each two arbitrary nodes, S_{bus} is set of system nodes.

C. Solving the Problem

The optimization problem is a nonlinear mixed-integer programming. GA is a population based, data based, and free-derivative method and takes the advantage of genetic operators, so that the chance of being involved in a local optimum is less in comparison with mathematical methods. Moreover, GA can easily consider the constraints. Therefore, GA is used in this paper. In what follows, the applied GA is briefly discussed. Each chromosome contains the number of switches that should be opened and the tap setting of transformers (Ts_i), see Figure 1. All genes are filled by integer values laid within the permitted limits, which are determined based on the system information.

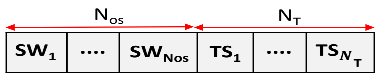

Figure 1. Typical structure of chromosomes

where, N_{os} is number of normally open switches, N_t is number of transformers.

Identifying the switches that should be opened, the system structure correspond to each chromosome is extracted. Afterward, constraints denoted by Equations (8) and (9) are cheeked. If the configuration is not verified, a large penalty is considered. Otherwise, based on the values of (TS_i) the voltage magnitude at low voltage side of transformers are derived. Then 24 backward/forward power flow solution [17] is run for feasible chromosomes to calculate the losses at each hour. Knowing the hourly market prices, the objective function can be calculated. All other constraints are checked based on the power flow results, and penalties are added if violations are occurred.

In reproduction process, roulette-wheel selection is applied to create the next generation. The crossover rate and the mutation rate are determined by test and also set approach as 0.7 and 0.2 respectively. The algorithm will be stopped if there is no improvement in objective function for a certain number of consecutive generation, which is set for each system by set and test approach.

III. NUMERICAL RESULTS

In order to evaluate the presented model, two distribution systems are applied. The first one is 33-bus test system presented in [18] used to validate the presented model. Then the system is modified as Figure 2 by categorizing the system loads to three groups, i.e. residential, commercial, and administrative and teaching center, to simulate the reality of practical distribution systems. The second one is a 33 kV practical feeder belongs to KEPDC which is used to evaluate the capability of the presented model for reducing the cost of loss in empirical systems.

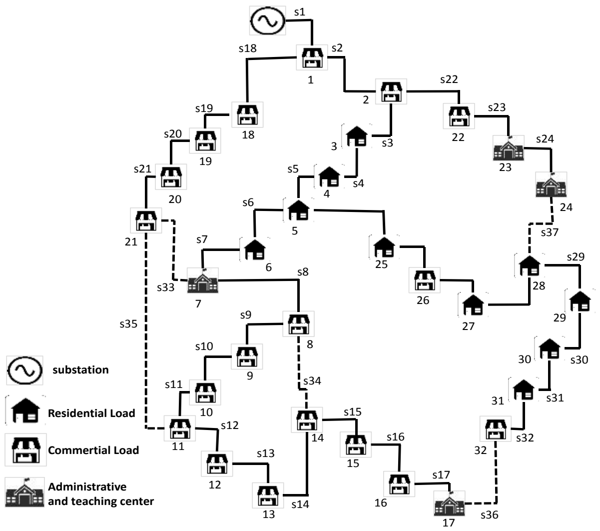

Figure 2. Modified 33-bus test system [18]

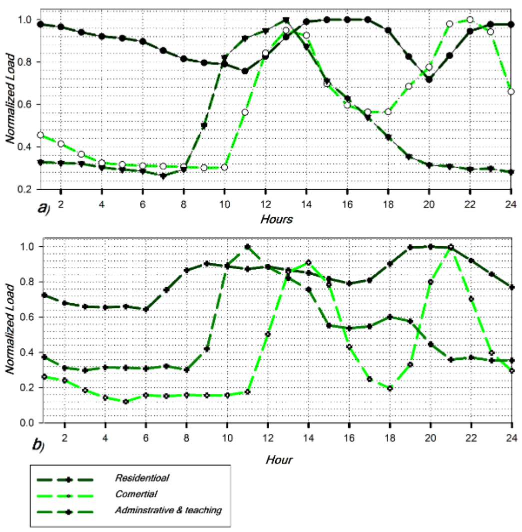

Figure 3. Normalized active load pattern, (a) warm season, (b) cold season

A. Model Validation

In order to validate the presented model, it is applied on original 33-bus test system with the aim of minimizing power losses (as the essential part of the presented algorithm) and the results are compared in Table 1 with references [10, 14]. As it is seen the best solution of the presented model is the same as one presented in [10, 14] and the algorithm is validated.

B. Case Studies on 33-Bus Test System

Modified 33-bus test system is taken into account. The load pattern of each load group is assumed to be the same as the corresponding load group in Iran, Khuzestan, see Figure 3. As well as, the peak load of each node is altered from the corresponding presented value in [18]. The hourly prices are shown in Table 2.

Table 1. Compression of presented model with references [10, 14] Regarding power loss reduction and 33-bus test system

33-bus network	Proposed algorithm	Ref. [10]	Ref. [14]
Open switches	7-9-14 32-37	7-9-14 32-37	7-9-14 32-37
Power losses (kW)	139.6	138.06	139.55
Minimum voltage (pu)	0.9378	0.9342	0.9378

Table 2. Hourly energy prices in $

Hour	1	2	3	4	5	6
Warm Season	0.0580	0.0542	0.0515	0.0501	0.0496	0.0490
Cold Season	0.0615	0.0590	0.0573	0.0566	0.0566	0.0567
Hour	7	8	9	10	11	12
Warm Season	0.0615	0.0504	0.0540	0.0566	0.0594	0.0641
Cold Season	0.0575	0.0598	0.0637	0.0659	0.0675	0.0682
Hour	13	14	15	16	17	18
Warm Season	0.0679	0.0685	0.0707	0.0700	0.0677	0.0659
Cold Season	0.0671	0.0658	0.0652	0.0649	0.0661	0.0697
Hour	19	20	21	22	23	24
Warm Season	0.0608	0.0598	0.0666	0.0763	0.0686	0.0612
Cold Season	0.0719	0.0700	0.0691	0.0688	0.0665	0.0635

B.1. Case 1: Importance of Objective Function

In order to indicate the importance of our objective function, the results should be compared with the case in which the goal is concentrated on reducing the power loss. In this respect, two scenarios are considered as follows:

Scenario 1- the objective function is minimizing the cost of power loss.

Scenario 2- the objective function is minimizing the cost of energy loss.

The reconfiguration problem is solved for modified 33-bus test system regarding both mentioned scenarios, and the results are presented in Tables 3 and 4 for cold and warm seasons respectively, see third and fifth column of each table. As it is seen in Table 3, for scenario 1, when minimization the cost of power loss is considered as objective function, the power loss of system is altered from 205.6813 kW in the initial configuration to 144.965 kW in the best configuration. While in the second scenario, the power loss reaches to 146.133 kW in best configuration.

Moreover, the total energy loss of system changes from 3059.9 kWh in the initial configuration to 2279.6 kWh and 2025.7 kWh in the best configurations of first and second scenarios respectively. Furthermore, reduction the cost of power loss in the first and second scenarios is 29.52% and 28.95% respectively. As well as reduction, the cost of energy loss in the first and second scenarios is 25.75% and 33.88% respectively. In brief, reduction the cost of energy loss in the best configuration of the first scenario is less than the second scenario, while the total power loss of the system (correspond to peak load) is more reduced in the first scenario in comparison with the second scenario. The same situation can be seen for cold season from Table 4. These results are summarized in Figure 4.

It should be mentioned that reducing the power loss and accordingly reducing the peak power is attractive from the view of system operator, however, the economical aspects are so important and need proper attention especially in the restructured power industry.

Table 3. Comparison the results of reconfiguration of 33-bus test system for warm season taking into account different objective functions, i.e. reduction the cost of power loss and reduction the cost of energy loss

Results	Warm Season				
	Initial Network Configuration	Reconfiguration with aim of reducing the cost of power losses (scenario 1)		Reconfiguration with aim of reducing the cost of energy losses (scenario 2)	
		Without Tap setting	With Tap setting	Without Tap setting	With Tap setting
Open switches	33-34-35-36-37	7-9-14-32-37	7-9-14-32-37	7-9-14-28-32	7-9-14-28-32
Slack bus voltage (pu)	1.0000	1.0000	1.0750	1.0000	1.0625
Power losses corresponding to maximum load (Kw)	205.6813	144.965	123.7504	146.1338	127.9843
Energy losses (Kwh)	3059.9	2279.6	1946.8	2025.7	1777.5
Cost of power losses corresponding to maximum load ($)	13.9678	9.8445	8.4038	9.9239	8.6914
Cost reduction (%)	----	29.52	39.83	28.95	37.77
Cost of energy losses ($)	189.8527	140.9555	120.3658	125.5365	110.1453
Cost reduction (%)	----	25.75	36.60	33.88	41.98
Minimum Voltage (pu)	0.9108 in h=14	0.9283 in h=14	1.0089 pu	0.9352 in h=14	1.0019 in h=13

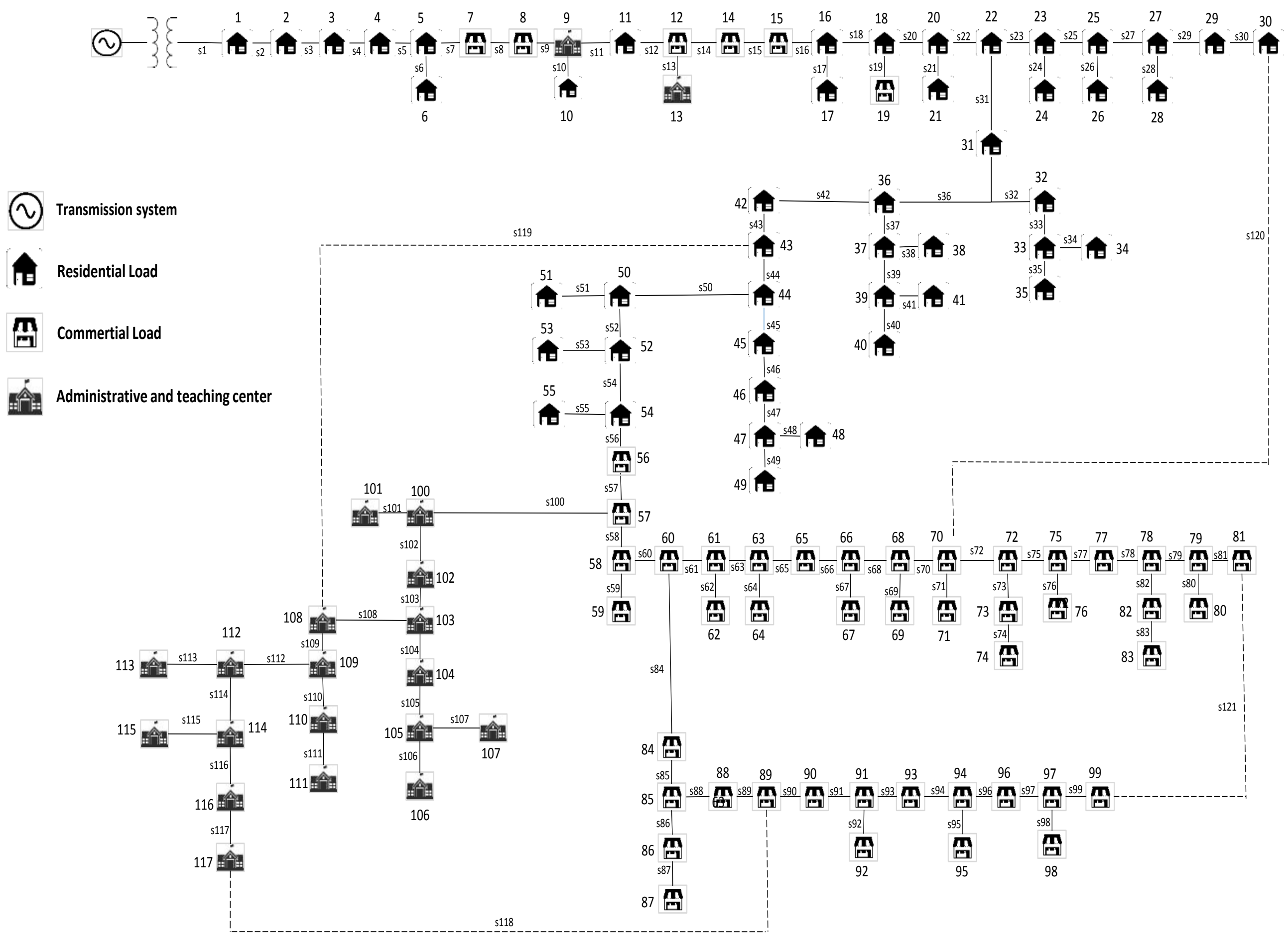

Figure 5. The 33 kV practical feeder belongs to KEPDC

B.2. Case 2: Study the Impact of Tap Setting on the Reconfiguration Result

In this case, the transformer taps are set along with reconfiguration problem regarding the previously mentioned scenarios in case 1. The number of tap steps is assumed to be 33 with tapping range of 10%.

The results are presented in Tables 3 and 4 for both warm and cold seasons respectively, see fourth and sixth columns of each table. As it is seen, in all cases, setting the tap step along with reconfiguration leads to improve the voltages and accordingly leads to greater cost reduction.

C. Application of Proposed Algorithm on a Practical System Belong to Khuzestan Electric Power Distribution Company (KEPDC)

The test system is a 33 kV feeder with four normally open switches belong to KEPDC, see Figure 5. The capacity of sub-transmission transformer is 12-16 MVA, and it contains 33 tap steps with tapping range of 10%. Total load of feeder for warm season is equal to 8.308 MW and 3.6891 MVar. The load patterns of different load groups are the same as Figure 3.

Since duration of warm season in Iran, Khuzestan is longer than cold season and also the consumption of warm season is very higher than cold season, in this sub-section only reduction the cost of energy loss in warm season is studied.

The results are provided in Table 5. As it is seen, after reconfiguration, the voltage margin of system is improved and the cost of energy loss is reduced by 16.64%. It is expected that applying this algorithm on whole network of KEPDC with peak load equal to 3000 MW lead to considerable cost saving.

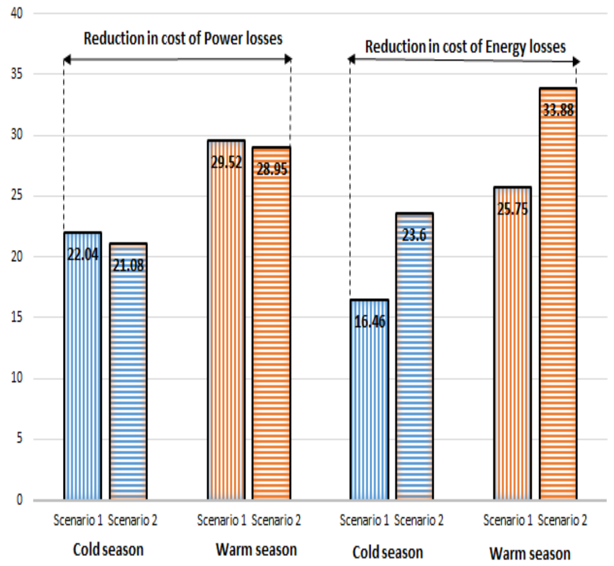

Figure 4. Comparing the reduction of cost of loss in modified 33-bus test system regarding both scenarios

Table 4. Comparison the results of reconfiguration of 33-bus test system for cold season taking into account different objective functions, i.e. reduction the cost of power loss and reduction the cost of energy loss

Results	Cold season				
	Initial Network Configuration	Reconfiguration with aim of reducing the cost of power losses (scenario 1)		Reconfiguration with aim of reducing the cost of energy losses (scenario 2)	
		Without Tap setting	With Tap setting	Without Tap setting	With Tap setting
Open switches	33-34-35-36-37	7-9-14-28-32	7-9-14-28-32	7-11-14-31-37	7-11-14-31-37
Slack bus voltage (pu)	1.0000	1.0000	1.0625	1.0000 p.u.	1.0563
Power losses corresponding to maximum load (kW)	25.0744	19.5430	17.2332	19.7857 kW	17.4390
Energy losses (kWh)	299.3804	250.5353	221.1032	228.4109 kWh	204.0560
Cost of power losses corresponding to maximum load ($)	1.8020	1.4047	1.2387	1.4221	1.2535
Cost reduction (%)	----	22.04	31.26	21.08	30.44
Cost of energy losses ($)	19.7753	16.5192	14.5782	15.1075 $	13.4960
Cost reduction (%)	----	16.46	26.28	23.60	31.75
Minimum Voltage (pu)	0.9668 in h=19	0.9743 in h=19	1.0384 in h=19	0.9659 in h=19	1.0300 in h=19

Table 5. The results of reconfiguration of practical system for reducing the cost of energy loss

Results:	Initial Network Configuration	Network Reconfiguration
Open switches	118-119-120-121	60-61-96-102
Slack bus voltage (pu)	1.0000	1.0688
Energy losses (MWh)	5.1518	4.2974
Losses cost ($)	322.0864	268.4962
Cost reduction (%)	----	16.64
Minimum voltage (pu)	0.9333	1.0117

IV. CONCLUSIONS

This paper develops an algorithm for seasonal reconfiguration of distribution network to minimize the cost of energy losses regarding hourly prices of energy. Daily load curves of different load categories, i.e. residential, commercial, and administrative and teaching center are considered and the tap setting is incorporated in the model. Numerical results show the impressiveness of the objective function regarding economical aspects in competitive environments. Moreover, tap setting along with reconfiguration may lead to improve the voltage margin and reduce the system cost. Thereby, it may cause more cost saving. Applying the presented model on a small part of KEPDC network shows the capability of the model for considerable cost saving in whole network.

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BIOGRAPHIES

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