This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/TIA.2022.3148061, IEEE Transactions on Industry Applications

An Efficient Model for Accurate Evaluation of Consumption Pattern in Distribution System Reconfiguration

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***Abstract*—Consumption patterns of electric power systems are important for distribution companies, because of their significant impact on energy losses amount. Therefore, some incentives are suggested by distribution companies to energy consumers for correcting their consumption manner. For a specific load pattern, distribution system reconfiguration (DSR) is an effective way to mitigate energy losses. Hence, some research works have included load variations in the DSR problem to show the importance of consumption patterns in reconfiguration decisions. However, some of the specialized literature has ignored load changes in their reconfiguration models due to the high computational burden and processing time. On the other hand, the energy losses are calculated inaccurately if the consumption pattern is neglected. Consequently, the main goal of this paper is to investigate load pattern impact on switching sequences to find out how much is load profile important for minimization of energy losses in DSR. The evaluations were carried out for three well-known distribution systems using a classic optimization tool, the A Mathematical Programming Language (AMPL).**

***Index Terms*—Consumption pattern, distribution network, reconfiguration, efficient mathematical model, energy losses.**

I. Introduction

Distribution system is one of the essential power network components [1]–[6] that plays an important role in power delivery [7], [8]. However, converting part of the distributed power to heat energy [9] can affect the operational costs and voltage profile. Hence, the reduction of power distribution losses is important for network users and operators [10].

The work of M. Mahdavi was funded by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior-Brasil (CAPES)-Finance Code 001. Also, M. Mahdavi would like to thank Prof. Ricardo Alan Verdú Ramos, director of Faculty of Engineering and coordinator of Associated Laboratory of IPBEN in São Paulo State University at Ilha Solteira, for providing the necessary facilities to carry out this work. Moreover, J.P.S. Catalão acknowledges the support by FEDER (COMPETE 2020) and FCT under POCI-01-0145-FEDER-029803 (02/SAICT/2017). (*Corresponding authors: F. Wang and J.P.S. Catalão*).

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One of the effective methods to decrease the energy losses is distribution system reconfiguration (DSR), where the topology of the network is changed by opening sectional switches and closing tie lines to find a suitable radial topology for providing the power demand of consumers [11]. In DSR, not only the minimization of power losses is important [12], but also voltage deviation, network adequacy [13]–[15], network stability [16], network reliability [17], [18], lines loading [19], [20], maintenance [21], load unbalances, renewable generation costs [22] and system restoration [23] can be optimized.

Many studies have been conducted on DSR with the aim of power losses reduction since 1975. In some of these studies, DC [24], AC [25], Newton [26], OPF [27], radial [28], simplified [29], and linearized [30]–[32] power flow methods have been applied to solve the DSR problem. In some of them, loss change estimation [33], network partitioning [34], [35], and Benders decomposition [36] strategies are suggested to formulate the problem. Also, in some others, linear [37], non-linear [38], integer [39], [40], and binary [41] programming models are proposed for DSR formulation. However, power demand changes have not been studied in all of these research works. To precisely calculate the energy losses, the demand variations have been included in the DSR problem by some specialized literature. Also, some studies considered load variations to determine real optimal reconfiguration plans.

Using actual variable load instead of a fix demand causes losses to be calculated correctly in static DSR, in which network configuration is determined at the beginning of the operation period. Also, power demand fluctuations lead to a change in reconfiguration plans in dynamic DSR, where distribution system topology is upgraded during the operation period based on load levels. Some research works claim that load variations affect reconfiguration plans in static DSR. However, considering load changes in reconfiguration models increases computational burden and time. In [42], power losses of the distribution system were minimized via network reconfiguration, while the load pattern was categorized as four levels and the load level of each bus was predicted by an artificial neural network (ANN). However, the efficiency of the proposed algorithm is reduced by choosing an improper training set for ANN. To resolve this issue, a clustering technique was employed in [43] to determine the best training set of ANN. Although the results of [42] and [43] confirmed that the distribution system topology changed with the load level in multi-stage (dynamic) reconfiguration problems, the reconfiguration plan dependency on load profile in static DSR was not addressed in [42] and [43].

Although the new strategy used in [43] improved the performance of ANN, clustering the loads based on their values without considering their locations can reduce the precision of the solution method. In [44], the daily load profile was considered for the minimization of losses cost and shunt capacitors investment in a simultaneous DSR and capacitor allocation problem. Actual demand was estimated by four load levels to improve the computational efforts of the algorithm. However, this estimation considerably decreased the accuracy of the calculations, because imprecise comparison of losses cost with capacitor investment affects the optimal place and number of capacitor banks and subsequent reconfiguration plans.

In [45], seasonal power demand was considered for the minimization of the losses and switching costs in network reconfiguration problems when distributed generation (DG) resources are utilized. Despite the demonstration of significant DG contribution in energy losses reduction, the obtained results are not accurate, because DG investment and operational costs have been ignored in the problem formulation. In [46], annual investment return was maximized through network reconfiguration considering weekly and seasonal load profiles. The investment return points to cost-savings due to loss reduction, communication equipment installation, and remote control switches maintenance. The results show that automatic switches save a large amount of investment by dynamically reconfiguring distribution systems. Load variations had to be considered in the problem formulation of [46] even if the computation burden and processing time increased because the problem is dynamic and the losses cost has been optimized in addition to other operational expenses.

Finally, in [47] and [48], the daily load profile was considered in the minimization of energy losses cost using an artificial immune system (AIS). The authors have shown that power demand variations affect the reconfiguration plans in static applications. Indeed, the configurations proposed by most of the previous studies have not included the load profile in their calculations. Consequently, an accurate evaluation of consumption pattern effect on reconfiguration decisions is necessary to determine if load variations are effective, so consumption patterns must be considered even for the minimization of power losses in the static reconfiguration studies.

Thus, the present paper comprehensively evaluates the load profile impact on distribution network reconfiguration using different consumption patterns and their combinations. The load variations manner is suitably formulated by different hourly load profiles in a mixed-integer conic programming (MICLP) problem using A Mathematical Programming Language (AMPL). The proposed model is thoroughly tested on three distribution systems using CPLEX solver in AMPL, which is a powerful optimization tool for engineering applications.

II. Load Patterns

Fig. 1 shows different consumption patterns for a distribution system during an operation period of 24 h. In these profiles, the vertical axis represents the power demand as a percentage of the system peak load.

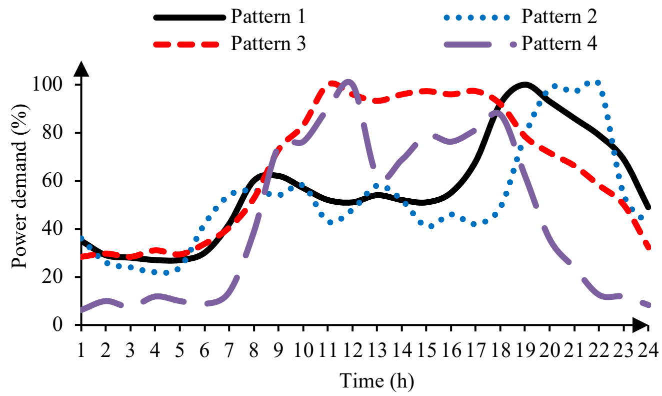

Fig. 1. Load patterns.

In static reconfiguration, usually, power demand of the distribution system is assumed to be fixed for the whole operation period to avoid high computational burden and efforts. On the other hand, power losses cannot be calculated accurately if load demand is not considered to be variable. This is a challenging problem for distribution system operators because considering the load profile in reconfiguration calculations increases the computational burden and ignoring it reduces computational accuracy. On the other side, [47] and [48] show that load patterns and changes impact reconfiguration plans and must be considered in DSR.

Accordingly, in this paper, the impacts of consumption patterns of Fig. 1 on the DSR problem are studied. Load patterns 2 to 4 have been adopted from [47], while consumption pattern 1 has been generated by the authors.

III. Mathematical Reconfiguration Model Considering Load Pattern

Aiming for the minimization of energy losses cost (C_{Loss}), the desired DSR problem that includes the load patterns of Fig. 1 can be described by the following equations [48].

$$Min\ C_{Loss} = \int_{t=1}^{t=24} C_L(t) \sum_{ij \in \Omega^l} R_{ij} \left| I_{ij}(t) \right|^2 dt \tag{1}$$

subject to:

$$P_i^S(t) + \sum_{ki \in \Omega^l} P_{ki}(t) - \sum_{ij \in \Omega^l} P_{ij}(t) - \sum_{ij \in \Omega^l} R_{ij} \left| I_{ij}(t) \right|^2 = P_i^D(t) \quad \forall i \in \Omega^b \tag{2}$$

$$Q_i^S(t) + \sum_{ki \in \Omega^l} Q_{ki}(t) - \sum_{ij \in \Omega^l} Q_{ij}(t) - \sum_{ij \in \Omega^l} X_{ij} \left| I_{ij}(t) \right|^2 = Q_i^D(t) \quad \forall i \in \Omega^b \tag{3}$$

$$\left| V_i(t) \right|^2 - \left| V_j(t) \right|^2 = 2\left[R_{ij} P_{ij}(t) + X_{ij} Q_{ij}(t) \right] + \left(R_{ij}^{\ 2} + X_{ij}^{\ 2} \right) \left| I_{ij}(t) \right|^2 + b_{ij}(t) \qquad \forall i,j \in \Omega^b, ij \in \Omega^l \tag{4}$$

$$\left| V_j(t) \right|^2 \left| I_{ij}(t) \right|^2 = P_{ij}^{\ 2}(t) + Q_{ij}^{\ 2}(t) \qquad \forall j \in \Omega^b, ij \in \Omega^l \tag{5}$$

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$$\sum_{ij\in\Omega^l} y_{ij} = \left|\Omega^b\right| - 1 \tag{6}$$

$$V_{\min}^2 \le \left|V_i(t)\right|^2 \le V_{\max}^2 \qquad \forall i\in\Omega^b \tag{7}$$

$$0 \le \left|I_{ij}(t)\right|^2 \le \left(I_{ij}^{\max}\right)^2 y_{ij} \qquad \forall ij\in\Omega^l \tag{8}$$

$$\left|b_{ij}(t)\right| \le \left(V_{\max}^2 - V_{\min}^2\right)\left(1-y_{ij}\right) \quad \forall ij\in\Omega^l \tag{9}$$

where Ω^l and Ω^b are set of distribution lines and buses, respectively. $C_L(t)$ is the cost per unit of energy losses at time t. $P_{ij}(t)$ and $Q_{ij}(t)$ are the active and reactive power flows of line ij at time t, respectively. R_{ij} is the resistance and X_{ij} is the reactance of line ij. $P_i^S(t)$, $Q_i^S(t)$, $P_i^D(t)$, and $Q_i^D(t)$ are active and reactive powers of substation and demand on bus i at time t, respectively. $\left|I_{ij}(t)\right|$ and $I_{ij}^{\max}$ are the current magnitudes of line ij at time t and its maximum value. $\left|V_i(t)\right|$, $V_{\max}$, and $V_{\min}$ are the voltage magnitude of bus i at time t and its maximum and minimum amounts, respectively, and $b_{ij}(t)$ is a variable representing the Kirchhoff's voltage law (KVL) in the loop formed by line ij at time t. Also, y_{ij} is a binary variable for the switch status of line ij (0 for open and 1 for closed switches).

Equations (2) and (3) express nodal active and reactive power balances at time t (Kirchhoff's current law, KCL). Equation (4) describes the net summation of voltage drops of all lines in a planar loop, which has to be equal to zero (KVL) at each time. In this equation, $b_{ij}(t)$ will be zero, when the switch of line ij is closed at time t (KVL must be established) and will be a real number for open switches (KVL is not necessary). Also, (5) shows the relationship between line power flow and its active and reactive components. Equation (6) indicates the radiality constraint. Thus, the total number of lines under operation (total number of closed switches) has to be equal to the total number of buses minus one (according to graph theory). Constraints (7) and (8) represent voltage and current limits, respectively. Eq. (9) makes sure that the value of $b_{ij}(t)$ will be zero, if the switch of line ij is closed (y_{ij}=1) and a real number between $V^2_{\max}-V^2_{\min}$ and $V^2_{\min}-V^2_{\max}$ when the corresponding line is disconnected (y_{ij}=0).

To convert the above-mentioned non-linear programming model to a convex mixed-integer non-linear optimization problem that can be accurately solved by linear commercial solvers in an acceptable computation time, (1) to (9) are modified as follows.

$$Min\ C_{Loss} = \sum_{h=1}^{24} C_L(h) \sum_{ij\in\Omega^l} R_{ij} I_{ij}^{sqr}(h) \tag{10}$$

subject to:

$$P_i^S(h) + \sum_{ki\in\Omega^l} P_{ki}(h) - \sum_{ij\in\Omega^l} P_{ij}(h) - \sum_{ij\in\Omega^l} R_{ij} I_{ij}^{sqr}(h) = P_i^D(h) \qquad \forall i\in\Omega^b \tag{11}$$

$$Q_i^S(h) + \sum_{ki\in\Omega^l} Q_{ki}(h) - \sum_{ij\in\Omega^l} Q_{ij}(h) - \sum_{ij\in\Omega^l} X_{ij} I_{ij}^{sqr}(h) = Q_i^D(h) \qquad \forall i\in\Omega^b \tag{12}$$

$$V_i^{sqr}(h) - V_j^{sqr}(h) = 2\left[R_{ij}P_{ij}(h) + X_{ij}Q_{ij}(h)\right] + \left(R_{ij}{}^2 + X_{ij}{}^2\right) I_{ij}^{sqr}(h) + b_{ij}(h) \quad \forall i,j\in\Omega^b, ij\in\Omega^l, h=1,\ldots,24 \tag{13}$$

$$y_{ij} = \beta_{ij} + \beta_{ji} \qquad \forall ij\in\Omega^l \tag{14}$$

$$\sum_{ij\in\Omega^l} \beta_{ij} = 1 \tag{15}$$

$$\beta_{ij} = 0 \qquad \forall i\in\Omega^s, ij\in\Omega^l \tag{16}$$

$$\beta_{ji} = 0 \qquad \forall j\in\Omega^s, ij\in\Omega^l \tag{17}$$

$$V_j^{sqr}(h) I_{ij}^{sqr}(h) \ge P_{ij}{}^2(h) + Q_{ij}{}^2(h) \quad \forall j\in\Omega^b, ij\in\Omega^l, h=1,\ldots,24 \tag{18}$$

$$V_{\min}^2 \le V_i^{sqr}(h) \le V_{\max}^2 \qquad \forall i\in\Omega^b, h=1,\ldots,24 \tag{19}$$

$$0 \le I_{ij}^{sqr}(h) \le \left(I_{ij}^{\max}\right)^2 y_{ij} \quad \forall ij\in\Omega^l, h=1,\ldots,24 \tag{20}$$

$$\left|b_{ij}(h)\right| \le \left(V_{\max}^2 - V_{\min}^2\right)\left(1-y_{ij}\right) \quad \forall ij\in\Omega^l, \forall h=1,\ldots,24 \tag{21}$$

$$\left|P_{ij}(h)\right| \le V_{\max} I_{ij}^{\max} y_{ij} \quad \forall ij\in\Omega^l \tag{22}$$

$$\left|Q_{ij}(h)\right| \le V_{\max} I_{ij}^{\max} y_{ij} \quad \forall ij\in\Omega^l \tag{23}$$

$$\sum_{ki\in\Omega^l} y_{ki} + \sum_{ij\in\Omega^l} y_{ij} \ge 1 \tag{24}$$

$$\sum_{ki\in\Omega^l} y_{ki} = \left|\Omega^b\right| - \left|\Omega^s\right| \tag{25}$$

where $I_{ij}^{sqr}(h)$ and $V_i^{sqr}(h)$ are the square of branch current and bus voltage magnitudes in hour h, respectively. Also, Ω^s is the set of substation buses, $P_{ij}(h)$ and $Q_{ij}(h)$ are hourly active and reactive power flows of line ij, respectively, and β_{ij} is the binary variable to show the direction of power flow in line ij. Equations (14) to (17) guarantee network radiality and connectivity in large distribution systems. Equation (16) indicates that if the start bus of a distribution line is connected to a substation, β_{ij} will be zero; β_{ji} is a binary number. If the end bus of the corresponding line is connected to the substation, β_{ji} is zero; β_{ij} is a binary number. In this case, distribution lines can be connected to the substation bus according to the values selected for variables β_{ij} and β_{ji}. Also, (22) and (23) describe active and reactive power flow limits for each line. Although constraints (19) and (20) provide these conditions, (22) and (23) improve the computation time and accuracy of the solutions. Moreover, (24) imposes that at least one branch has to be connected to every bus. It means that topologies with isolated buses are ignored during reconfiguration, which in fact reduces the search space of the solution algorithm significantly. Finally, (25) indicates that the total number of closed switches should be equal to the difference of the total number of nodes with substation buses.

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IV. Simulation Results

To have an accurate evaluation of consumption pattern role in distribution network reconfiguration, the proposed model was tested on 33-bus [28], 84-bus [50], and 136-bus [51] distribution systems with single-line diagrams of Figs 2 to 4 using CPLEX in AMPL.

The per unit energy losses costs of [47] were chosen according to Table I. The same load levels used in [47] were selected as load patterns in Table I.

The peak load of each bus should be multiplied by the hourly demand percentage to obtain the load levels of the corresponding bus in each hour. The results of the proposed model, such as network configuration (open switches), daily energy losses cost ($), and computation time (s) are listed in Tables II to XIV for all test systems. According to [47], it is assumed that 60%, 25%, and 15% of the consumers have load patterns 2 to 4, respectively. Load patterns 2 to 4 are related to residential, commercial, and industrial load profiles, as mentioned in [47].

It should be noted that the selection of the type of consumer at each node has been done randomly in [47], assuming that 60% of the consumers are residential, 25% are commercial, and 15% are industrial. In this paper, the same load profile combination (60% of consumers have load pattern 2, 25% of them have load pattern 3, and 15% have load pattern 4) and per unit energy losses costs as [47] are used without random assignment of load patterns. The load assignment is not the main topic of the present paper, but the proposed model was tested on example networks with two different load profile combinations.

From Tables II, III and IV, it can be seen that the proposed approach and models presented in [47] and [48] suggest the same optimal configurations for a fix load amount and reduce the energy losses cost-efficiently after reconfiguration, in which the peak load has been considered as a fixed demand during the whole operation period.

According to these tables, losses costs are reduced by 31% for the 33-bus test system and by 12% for 84-bus and 136-bus distribution networks.

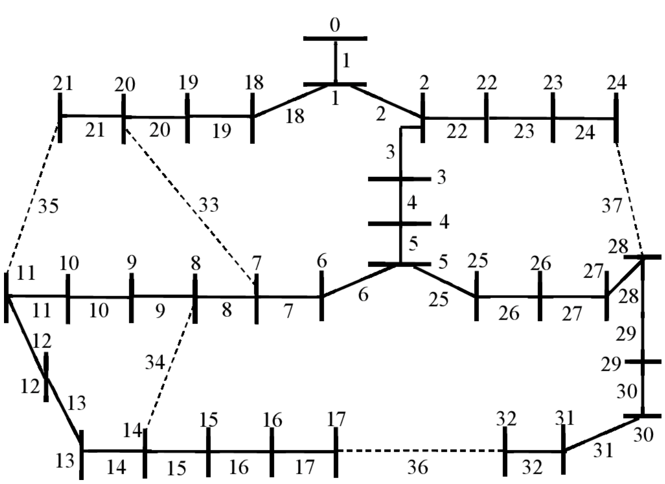

Fig. 2. 33-bus test system.

TABLE I
DATA OF LOAD PATTERNS AND COSTS PER UNIT OF ENERGY LOSSES

Hour	Demand Percentage of Load Patterns (%)				Cost
	1	2	3	4	($/kWh)
1	35	36	28.38	6.25	0.065
2	29	26	29.73	10	0.065
3	28	24	28.38	7.5	0.065
4	27	22	31.08	11.88	0.065
5	27	24	29.38	10	0.065
6	30	42	33.78	8.75	0.065
7	42	54	40.54	13.75	0.11
8	60	56	52.7	38.75	0.11
9	62	54	72.97	74.38	0.11
10	57	58	83.11	76.25	0.11
11	52	43	100	90	0.11
12	51	48	95.95	100	0.11
13	54	58	93.24	61.88	0.11
14	52	52	95.95	68.75	0.11
15	51	41	97.3	78.75	0.13
16	55	46	95.95	76.25	0.13
17	68	42	97.3	81.25	0.13
18	92	49	91.89	87.5	0.13
19	100	79	78.38	61.88	0.15
20	93	98.4	71.62	35.63	0.15
21	86	97	66.22	23.75	0.15
22	79	100	58.11	12.5	0.065
23	69	54	50	11.88	0.065
24	49	42	32.29	8.32	0.065

TABLE II
RECONFIGURATION RESULTS OF 33-BUS TEST SYSTEM FOR FIXED LOAD

Model		Configuration	Energy Losses Cost ($)
Proposed	Before Reconfiguration	33,34,35,36,37	493.5
	After Reconfiguration	7,9,14,32,37	339.8
[47]	Before Reconfiguration	33,34,35,36,37	493.5
	After Reconfiguration	7,9,14,32,37	339.8
[48]	Before Reconfiguration	33,34,35,36,37	493.5
	After Reconfiguration	7,9,14,32,37	339.8

TABLE III
RECONFIGURATION RESULTS OF REAL 84-BUS DISTRIBUTION NETWORK FOR FIXED LOAD

Model		Configuration	Energy Losses Cost ($)
Proposed	Before Reconfiguration	84,85,86,87,88,89,90, 91,92,93,94,95,96	1295.45
	After Reconfiguration	7,13,34,39,42,55,62, 72,83,86, 89,90,92	1144.15
[47]	Before Reconfiguration	84,85,86,87,88,89,90, 91,92,93,94,95,96	1295.45
	After Reconfiguration	7,13,34,39,42,55,62, 72,83,86, 89,90,92	1144.15
[48]	Before Reconfiguration	84,85,86,87,88,89,90, 91,92,93,94,95,96	1295.45
	After Reconfiguration	7,13,34,39,42,55,62, 72,83,86, 89,90,92	1144.15

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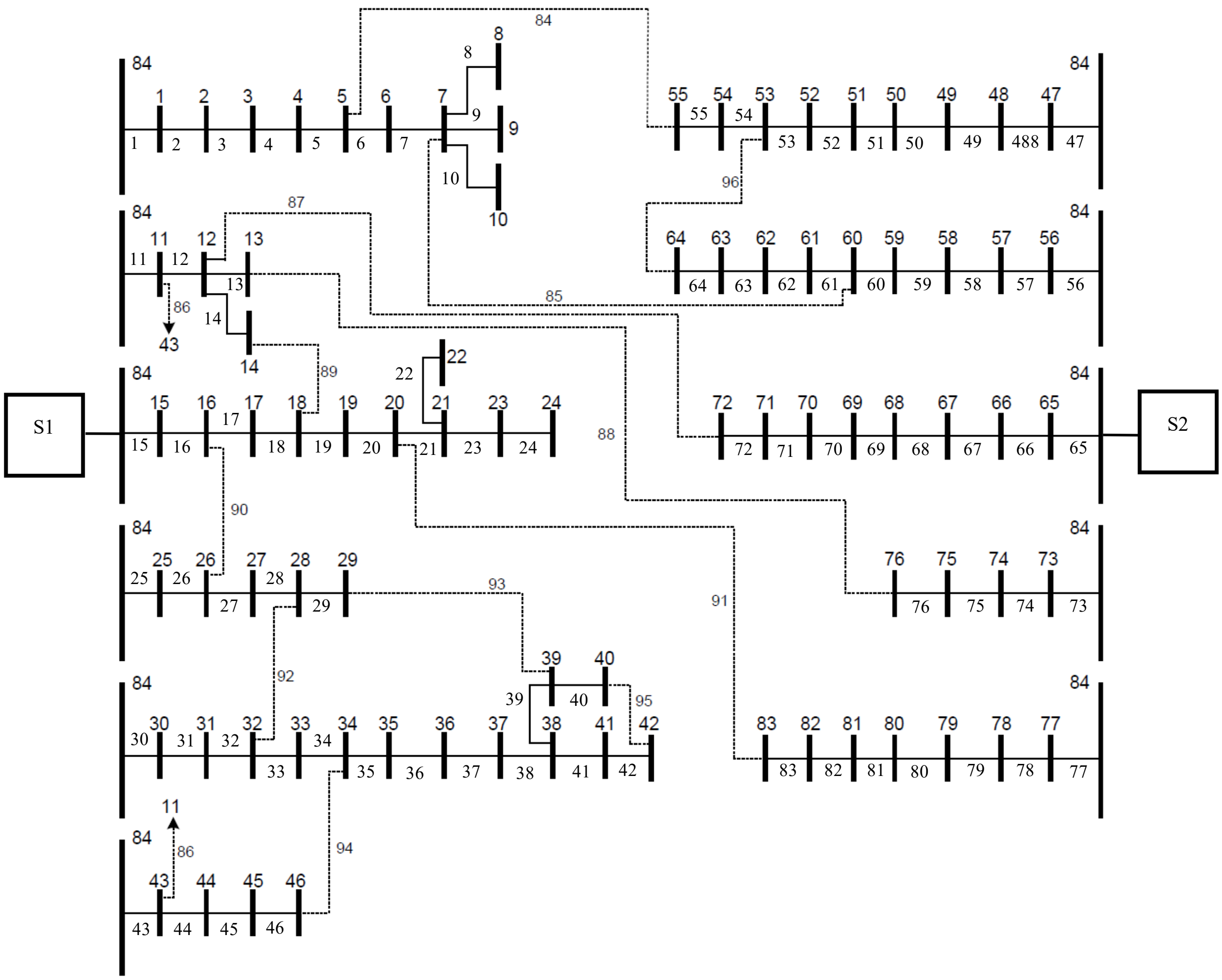

Fig. 3. 84-bus distribution system.

TABLE IV
RECONFIGURATION RESULTS OF ACTUAL 136-BUS DISTRIBUTION NETWORK FOR FIXED LOAD

Model		Configuration	Energy Losses Cost ($)
Proposed	Before Reconfiguration	136,137,138,139,140,141,142,143, 144,145,146,147,148,149,150,151, 152,153, 154,155,156	780.1
	After Reconfiguration	7,35,51,90, 96,106,118, 126,135,137,138,141,142, 144,145,146,147,148, 150,151,155	682.3
[47]	Before Reconfiguration	136,137,138,139,140,141,142,143, 144,145,146,147,148,149,150,151, 152,153, 154,155,156	780.1
	After Reconfiguration	7,38,51,54,84,90,96,106,118, 126,135,137,138,141,144,145, 147,148,150,151,155	682.3
[48]	Before Reconfiguration	136,137,138,139,140,141,142,143, 144,145,146,147,148,149,150,151, 152,153, 154,155,156	780.1
	After Reconfiguration	7,38,51,54,84,90,96,106,118, 126,135,137,138,141,144,145, 147,148,150,151,155	682.3

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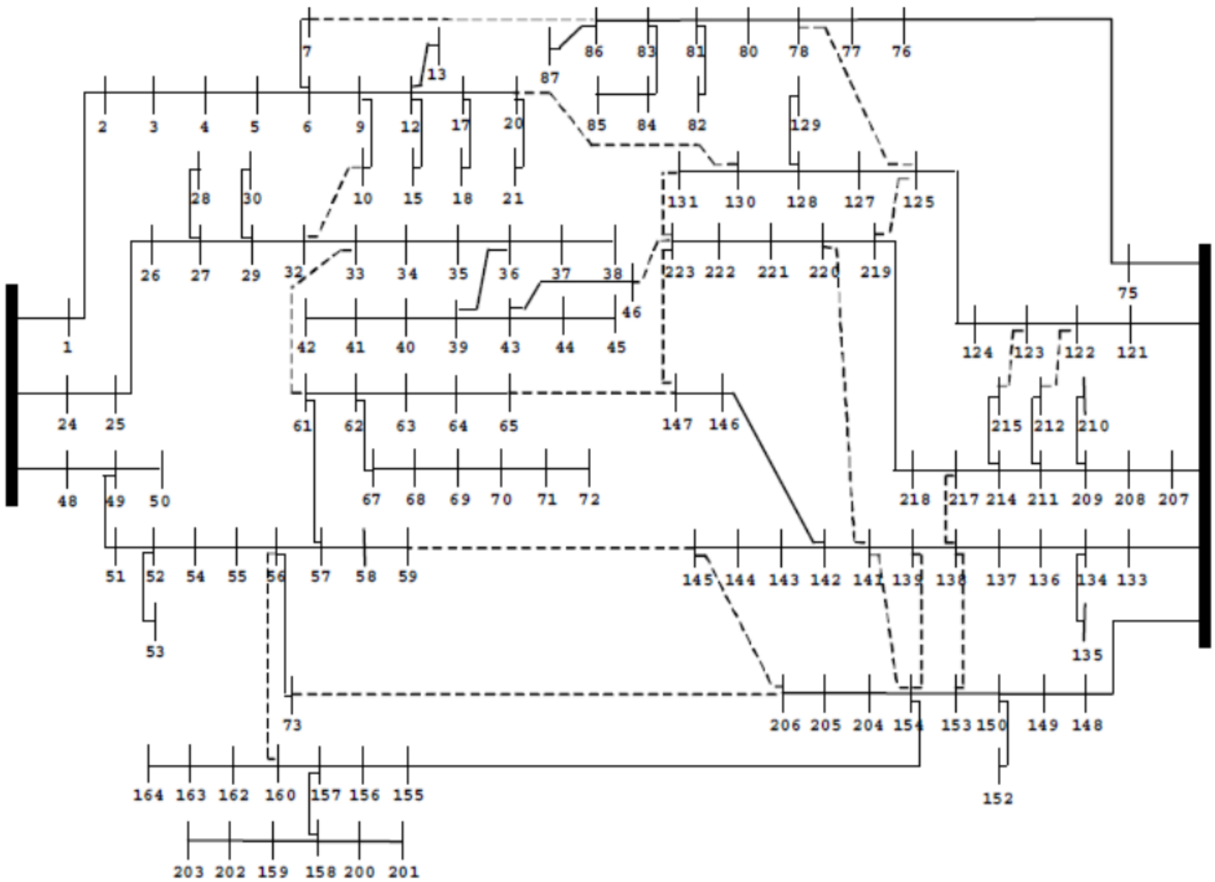

Fig. 4. 136-bus distribution system [51].

The consumption pattern of each load point is achieved by multiplying the weighted sum of load patterns 2 to 4 by the peak load of the corresponding bus. In simple terms, summation of load patterns 2 to 4 with weighted factors 0.6, 0.25, and 0.15 for load combination 1 or 0.15, 0.25, and 0.6 for load combination 2, respectively, are multiplied by the peak load of each bus.

Moreover, Tables V to VII indicate that the proposed model can find better configurations with fewer power losses than those of [47] and [48] when different load patterns are considered instead of a fixed load amount.

In other terms, the radial topologies suggested by the proposed model cause more cost savings than the configurations presented in [47] and [48].

Comparing the results of Tables V to VII with those of Tables II to IV, respectively, explain that considering consumption patterns in the reconfiguration of distribution systems reduces the cost of energy losses significantly but it cannot change the network configuration (reconfiguration plans).

TABLE V

RECONFIGURATION RESULTS OF 33-BUS TEST SYSTEM FOR THE LOAD COMBINATION 1 AT EACH BUS: 60% OF CONSUMERS WITH LOAD PATTERN 2, 25% WITH LOAD PATTERN 3, AND 15% WITH LOAD PATTERN 4

Model		Configuration	Energy Losses Cost ($)
Proposed	Before Reconfiguration	33,34,35,36,37	175.6
	After Reconfiguration	7,9,14,32,37	123.1
[47]	Before Reconfiguration	33,34,35,36,37	175.6
	After Reconfiguration	7,9,14,28,32	128.8
[48]	Before Reconfiguration	33,34,35,36,37	175.6
	After Reconfiguration	7,9,14,28,32	128.8

TABLE VI

RECONFIGURATION RESULTS OF 84-BUS DISTRIBUTION NETWORK FOR THE LOAD COMBINATION 1 AT EACH BUS: 60% OF CONSUMERS WITH LOAD PATTERN 2, 25% WITH LOAD PATTERN 3, AND 15% WITH LOAD PATTERN 4

Model		Configuration	Energy Losses Cost ($)
Proposed	Before Reconfiguration	84,85,86,87.88.89,90, 91,92,93,94,95,96	470.1
	After Reconfiguration	7,13,34,39,42,55,62, 72,83,86,89,90,92	417.6
[47]	Before Reconfiguration	84,85,86,87.88.89,90, 91,92,93,94,95,96	470.1
	After Reconfiguration	7,34,39,63,72,83,84, 86,88,89,90,92,95	418.2
[48]	Before Reconfiguration	84,85,86,87.88.89, 90, 91,92,93,94,95,96	470.1
	After Reconfiguration	7,34,39,63,72,83,84, 86,88,89,90,92,95	418.2

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TABLE VII
RECONFIGURATION RESULTS OF 136-BUS DISTRIBUTION NETWORK FOR THE LOAD COMBINATION 1 AT EACH BUS: 60% OF CONSUMERS WITH LOAD PATTERN 2, 25% WITH LOAD PATTERN 3, AND 15% WITH LOAD PATTERN 4

Model		Configuration	Energy Losses Cost ($)
Proposed	Before Reconfiguration	136,137,138,139, 140,141,142,143, 144,145,146,147, 148,149,150,151, 152,153,154,155, 156	284.1
	After Reconfiguration	7,35,51,90,96,106, 118,126,135,137, 138,141,142,144, 145,146,147,148, 150,151,155	250.23
[47]	Before Reconfiguration	136,137,138,139, 140,141,142,143, 144,145,146,147, 148,149,150,151, 152,153,154,155, 156	284.1
	After Reconfiguration	7,38,51,54,84,90, 96,106,118,126, 135,137,138,141, 144,145,147,148, 150,151,155	250.41
[48]	Before Reconfiguration	136,137,138,139, 140,141,142,143, 144,145,146,147, 148,149,150,151, 152,153,154,155, 156	284.1
	After Reconfiguration	7,38,51,54,84,90, 96,106,118,126, 135,137,138,141, 144,145,147,148, 150,151,155	250.41

TABLE VIII
RECONFIGURATION RESULTS OF 33-BUS TEST SYSTEM FOR THE LOAD COMBINATION 2 AT EACH BUS: 15% OF CONSUMERS WITH LOAD PATTERN 2, 25% WITH LOAD PATTERN 3, AND 60% WITH LOAD PATTERN 4

Model		Configuration	Energy Losses Cost ($)
Proposed	Before Reconfiguration	33,34,35,36,37	181.1
	After Reconfiguration	7,9,14,32,37	126.5

TABLE IX
RECONFIGURATION RESULTS OF 84-BUS DISTRIBUTION NETWORK FOR THE LOAD COMBINATION 2 AT EACH BUS: 15% OF CONSUMERS WITH LOAD PATTERN 2, 25% WITH LOAD PATTERN 3, AND 60% WITH LOAD PATTERN 4

Model		Configuration	Energy Losses Cost ($)
Proposed	Before Reconfiguration	84,85,86,87.88.89,90, 91,92,93,94,95,96	482.9
	After Reconfiguration	7,13,34,39,42,55,62, 72,83,86,89,90,92	428.5

TABLE X
RECONFIGURATION RESULTS OF 136-BUS DISTRIBUTION NETWORK FOR THE LOAD COMBINATION 2 AT EACH BUS: 15% OF CONSUMERS WITH LOAD PATTERN 2, 25% WITH LOAD PATTERN 3, AND 60% WITH LOAD PATTERN 4

Model		Configuration	Energy Losses Cost ($)
Proposed	Before Reconfiguration	136,137,138,139, 140,141,142,143, 144,145,146,147, 148,149,150,151, 152,153,154,155, 156	291.64
	After Reconfiguration	7,35,51,90,96,106, 118,126,135,137, 138,141,142,144, 145,146,147,148, 150,151,155	256.54

TABLE XI
COMPUTATIONAL TIME OF THE PROPOSED MODEL FOR FIXED AND VARIABLE LOADS

System	Computation Time (s)		
	Fixed load	Variable load	
		Load Combination 1	Load Combination 2
33	3.26	15.68	18.03
84	2.7	34.23	23.02
136	7.06	203.49	251.33

TABLE XII
RECONFIGURATION RESULTS OF 33-BUS TEST SYSTEM FOR DIFFERENT LOAD PROFILES

Load Pattern	Configuration	Energy Losses Cost ($)
1	7,9,14,32,37	137.9
2	7,9,14,32,37	117.2
3	7,9,14,32,37	190.3
4	7,9,14,32,37	118.7

TABLE XIII
RECONFIGURATION RESULTS OF 84-BUS DISTRIBUTION NETWORK FOR DIFFERENT LOAD PROFILES

Load Pattern	Configuration	Energy Losses Cost ($)
1	7,13,34,39,42,55,62,72,83,86,89,90,92	467.12
2	7,13,34,39,42,55,62,72,83,86,89,90,92	397.13
3	7,13,34,39,42,55,62,72,83,86,89,90,92	642.80
4	7,13,34,39,42,55,62,72,83,86,89,90,92	401.73

TABLE XIV
RECONFIGURATION RESULTS OF 136-BUS DISTRIBUTION NETWORK FOR DIFFERENT LOAD PROFILES

Load Pattern	Configuration	Energy Losses Cost ($)
1	7,35,51,90, 96,106,118,126,135,137,138, 141,142,144,145,146,147,148,150,151,155	279.6
2	7,35,51,90, 96,106,118,126,135,137,138, 141,142,144,145,146,147,148,150,151,155	237.8
3	7,35,51,90, 96,106,118,126,135,137,138, 141,142,144,145,146,147,148,150,151,155	384.2
4	7,35,51,90, 96,106,118,126,135,137,138, 141,142,144,145,146,147,148,150,151,155	240.3

Even though the models of [47] and [48] could find different radial topologies from the fixed load situation, their proposed configurations are not accurate and are not as optimal as the topologies found by the proposed model. Therefore, it can be said that considering the load pattern should not change the reconfiguration plans even if each hour has a different cost of energy losses, because the proposed topologies have to meet the maximum peak load of all consumers. The results of Tables VIII to X and XII to XIV confirm this reality because the same configurations are proposed for different consumption patterns. Therefore, these tables describe the important role of power demand variations and load patterns in energy losses calculations.

Table XI shows that the computational burden and processing time of the model increase with considering load profile in DSR calculations. Therefore, solving the DSR problem for fixed load is adequate if the goal is just finding the best configuration with the minimum power or energy losses or the lowest energy losses cost. Whereas if the aim is to optimize energy losses or its cost compared to other operational or investment expenses, the load profile and consumption pattern have to be considered.

V. Conclusion

Regarding the important role of the load pattern and electrical energy consumption manner in power losses reduction, electric companies give discounts to network users if they modify their consumption behavior according to company recommendations. Distribution system reconfiguration (DSR) is an effective method for energy losses minimization, especially when load profile is considered. Recently, few research works tried to study this important point in the reconfiguration of distribution networks. However, considering load variations in the reconfiguration problem increases the computational efforts in large and real distribution systems. Therefore, this paper evaluated the role of consumers' manner and load pattern in DSR. The simulation results indicate that the load profile and consumers' behavior influence the energy losses cost significantly, but cannot change the switching sequences (network configurations). It should be mentioned that if the DSR problem is going to be solved for the minimization of power losses or losses cost, network reconfiguration should be carried out according to the peak load level without considering the consumption pattern. However, the load profile must be considered when other operational and/or investment costs are optimized beside losses, because power losses amount affects the results and may change the reconfiguration topologies.

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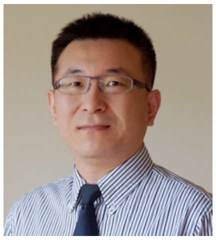

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