# Impact of Active Network Management in Operation of Tabriz Distribution System

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*Abstract*—**This paper proposes a new paradigm for distribution system operation under Active Network Management (ANM). The ANM method has essential role to facilitate the connection of new generations without need of reinforcement traditional network. This paper presents a cost function based on active management that minimize energy cost of Distribution Network Operator (DNO). The proposed objective function is determined based on optimal power flow and with considering the technical constraints. The results of ANM method are compared with the Passive Management (PM). The analysis was carried out successfully considering a real 29-bus urban distribution network in Iran. This paper uses GAMS software to solve the short-term operation problem on case study.**

## 1. Introduction

In deregulated electrical market, the technical and economic issues of DGs integration have attracted the focus of academic research in recent years. Hence, several researchers, over the past decade, have investigated the penetration effects of the DG units on the distribution network [1]. DG development will have a major effect on the short-term operation of distribution network. In the most cases, distribution networks are expanded in a radial form. The voltage profile and power losses are the major problem raised in the passive networks [2]. In the passive networks, regardless of whether DG is connected to the network or not, DNOs continues operation of their network distribution with previous method. This means that the capacity of DG connecting with the distribution network is limited rigidly by DNOs in order to avoid negative effects due to high level penetration [3]. In contrast, active management is an impressive approach for network reinforcement in the operation of DG. Use of Active Network Management (ANM) besides the increase of penetration level of DG and the reduction of losses can assist in modification of load pick, control of voltage, improvement of DG curtailment, and postponement of the distribution networks' reinforcement [2, 4]. Therefore, it should be noted that active management of distribution network through different researches has been discussed. Active management proposes tools for real time control and management of distribution system using online measurement and communication systems [5]. In [6], an algorithm for implementation of the active management of network in order to minimize the defined cost function is presented. In [7], the voltage regulation issue at the radial MV distribution networks has been studied.

The proposed objective function is placed based on minimizing the costs of DNO. In this function, cost of the energy supplied by transmission network and plus cost of energy generated by DGs and RPCs are calculated. Through executing the AM programs for optimal operation of distribution network, the power losses cost and the defined cost function will reduce.

The main contributions of this paper are:

1) Active management of distribution network are suggested to determine the optimal short-term operation of distribution network along with the DG units.

2) The objective function is successfully applied to a real 29-bus urban distribution network in Iran for a daily period.

In Section 2, ANM concept is expressed. The mathematical formulation is described in Section 3. Assumptions of problem and descriptions of distribution systems are presented in Section 4. In Section 5, the proposed model is applied on a realistic 29-bus distribution system, and also the obtained results is presented and discussed. Finally, conclusions are drawn in the Section 6.

## 2. Active Network Management

In the ANM method, a central controller system for distribution network can be considered. This Distribution Management System (DMS) allows DG to be connected to the distribution network without increasing in the voltage of network. At different levels, will be possible integration and coordination between remote controller (DMS which located in primary substation) and local controllers. DMS is represented in Fig. 1. According to Fig. 1, state estimation algorithm is applied in distribution network which receives the load measures through the local and remote measurements. Network data and pseudo measures are the other inputs of the state estimator. The active controller (or coordinated controller) will issue the control commands.
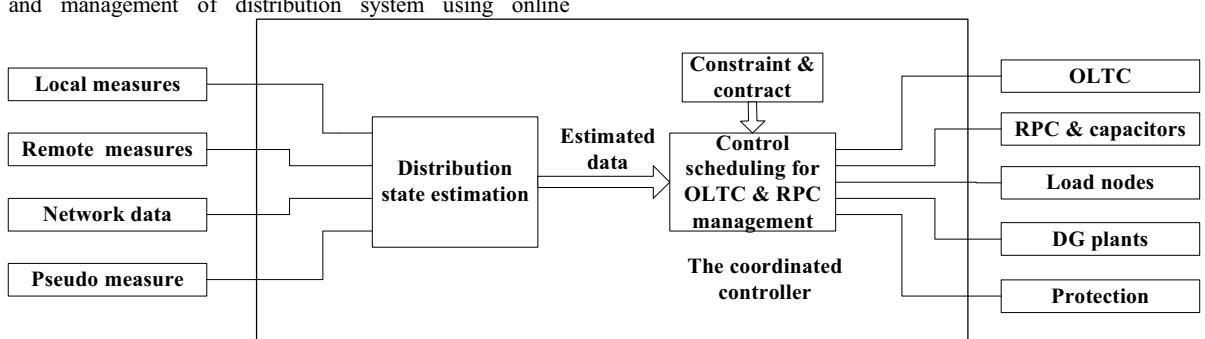


Fig.1. Block diagram of DMS in active distribution network

To enhance the installable capacity of DGs along with keeping the voltage in the permissible range, three ANM strategies is applied as follows [8]:

- Voltage control by on-load-tap-changer (OLTC);
- Using the reactive power compensator (RPC);
- Active power management of DG.

In this paper, three modes for distribution network have been presented:

Mode1. Conventional distribution networks: Power flow is unidirectional from high voltage (HV) transmission network to customers in low voltage levels. In this mode, No DG is connected to the network.

Mode2. Passive distribution networks with DG: In these networks, installable capacity of DG is available to radial network. Unidirectional power flow may change to bidirectional power flow when the penetration level of DG becomes high. AM is not applied, and the outputs of DG units are not controlled by DNO.

Mode3. Active distribution networks with AM programs: In this scenario, in addition to the installable DG in distribution network, AM programs will be implemented for optimal operation of the distribution network.

## 3. Problem Formulation

In this section, a model for the operation of distribution network in the presence of DG units is presented. This model is based on optimal power flow and minimizes the energy costs of DNO for a daily short-term period. In the proposed model for the objective function, DNO is assumed the owner of DG units. Therefore, planning and dispatch of these units is done by DNO. The operation of distribution networks with DG for passive networks is compared with active networks. This model is based on the variation of the daily load curve.

### 3.1. Load & electricity price model

The load variation curve is modeled by multiplication of two-parameter. The first one is base load ($S_{i,base}^D$) and any hours a day is defined as a load level. Then each day is divided into $N_{dlf}$ demand levels. A demand level factor ($DLF_h$) is defined in order to determine a forecasted value of "load to peak load ratio" in each demand level which varies between 0 and 1. Demand level factor is shown in Fig. 2 which is a real curve in Tabriz city, located in Iran. Therefore, demand in $i^{th}$ bus, $h^{th}$ demand level is calculated as follows [9]:

$$P_{i,h}^D = P_{i,base}^D \times DLF_h$$
$$Q_{i,h}^D = Q_{i,base}^D \times DLF_h \quad (1)$$
$$S_{i,h}^D = P_{i,h}^D + jQ_{i,h}^D$$

The price of energy purchased from the main grid is not considered identical for different demand levels. Hence generally we assume that the price of electricity in $h^{th}$ demand level can be determined as follows [9]:

$$\lambda_h = \rho \times PLF_h \quad (2)$$

where $\rho$ is base price and $PLF_h$ is $h^{th}$ price level factor. For simplicity, we assume that for load levels, $PLF_h$ curve is considered such as $DLF_h$ curve.

### 3.2. Objective function

The operation model of distribution network in the presence of DG is optimal combination of the DG units and other energy sources which are included power losses. The objective function minimizes the energy costs for a day. The cost function is expressed by Eq. 3.
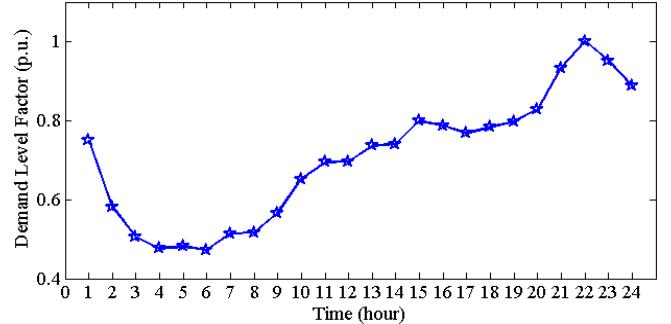


Fig. 2. Demand level factor for daily short-term period

$$F = \sum_{t=1}^{N_h} [\sum_{i=1}^{N_{SS}} \rho^P \times P_i + \sum_{i=1}^{N_{SS}} \rho^Q \times Q_i + \sum_{i=1}^{N_{DG}} (A_i P_i^2 + B_i P_i + C_i)$$
$$+ \sum_{i=1}^{N_{DG}} Q_i \times CT_i^Q + P_{loss}^{Total}] \quad (3)$$

The first term is cost of the purchased power from external network or the energy market, and its value depends on the electricity market price ($\rho^P$). Prediction of the market price is the out of debate. For simplicity, it is assumed that DNO predicts the market price based on the past experience or the provided data by market operator. The second term is the amount paid for reactive power from the external network which is described in a pre-determined price ($\rho^Q$). The third and fourth terms represent operating costs for active and reactive power of the DG units, respectively. Here, the simple structure of the DG units for reactive power is considered. The last term describes the total loss of the network in each hour.

### 3.3. Constraints and optimal power flow equations:

The power flow equations must be satisfied in $i^{th}$ bus, $h^{th}$ hours as follows:

$$P_h^{ss} + P_{i,h}^{DG} - P_{i,h}^D = V_{i,h} \sum_j V_{j,h} (G_{ij} \cos\delta_{i,h} + B_{ij} \sin\delta_{j,h}) \quad (4)$$

$$Q_h^{ss} + Q_{i,h}^{DG} - Q_{i,h}^D = V_{i,h} \sum_j V_{j,h} (G_{ij} \cos\delta_{i,h} - B_{ij} \sin\delta_{j,h}) \quad (5)$$

where $P_h^{ss}$ and $Q_h^{ss}$ are active and reactive power generated (or absorbed) by substation in $h^{th}$ hours. $\widetilde{V}_{i,h}$ and $\delta_{i,h}$ show the magnitude and angle of voltage in $i^{th}$ bus, $h^{th}$ hours, respectively.

The voltage of each bus in $h^{th}$ hours should be kept into the safe operating limits.

$$V_i^{min} \leq V_{i,h} \leq V_i^{max} \quad (6)$$

The active and reactive power limits of the substation are proportional to the one capacity as follows [10]:

$$P_{ss}^{min} \leq P_h^{ss} \leq P_{ss}^{max} \quad (7)$$

$$Q_{ss}^{min} \leq Q_h^{ss} \leq Q_{ss}^{max} \quad (8)$$

The DG units should be operated with considering the limits of their maximum installed capacity [10]:

$$P_{DG}^{\min} \le P_{i,h}^{DG} \le P_{DG}^{\max} \qquad (9)$$

The power factor of DG units for all demand levels is assumed to be constant [11]:

$$\cos \varphi = \frac{P_{i,h}^{DG}}{\sqrt{\left(P_{i,h}^{DG}\right)^2 + \left(Q_{i,h}^{DG}\right)}} = const. \qquad (11)$$

The thermal constraint in the line connected to nodes i, j for all demand levels and each year should be in permissive limits.

$$S_{ij,t,h} \le S_{ij}^{\max} \qquad (12)$$

The tap setting of tap-changer $k$ at $h^{th}$ demand level is assumed as follows:

$$T_k^{\min} \le T_{k,h} \le T_k^{\max} \qquad (13)$$

## 4. Assumptions and Description of Case Study

### 4.1. Assumption of problem

The proposed model is applied on a 20-kV, 29-bus distribution network. The distribution network operation will be carried out along with the two DG units. DG1 and DG2 are installed at bus 15, 26, respectively. The operational period is 24 hours. Base price of the purchased energy from the network is assumed to be equal 120 dollars per MWh. Duration of each load level is equal to one hour. The rest of the parameters used in problem are listed in Tables 1 and 2.

### 4.2. Descriptions of real 29-bus urban distribution network

Simulation on real urban distribution network is performed. The network is a 20kV feeder in the Tabriz city located in Iran and shown in Fig. 3. The voltage level of the substation and capacity of the feeder are 20 kV and 16 MVA, respectively. It is assumed that RPC1 and RPC2 are installed at the node 15 and 26 with the size of 3200 and 400Kvar, respectively. Network data are given in Table 3. Peak load is occurred in 10885Kw and 5207Kvar.

TABLE 1. COMMERCIAL AND TECHNICAL INFORMATION

| Bus with DG | A ($/MW$^2$) | B ($/MW) | C ($) | $CT_i^Q$ ($/Mvar) |
|---|---|---|---|---|
| 15 | 0/0075 | 60 | 45 | 7 |
| 26 | 0/0075 | 84 | 58/5 | 8/5 |
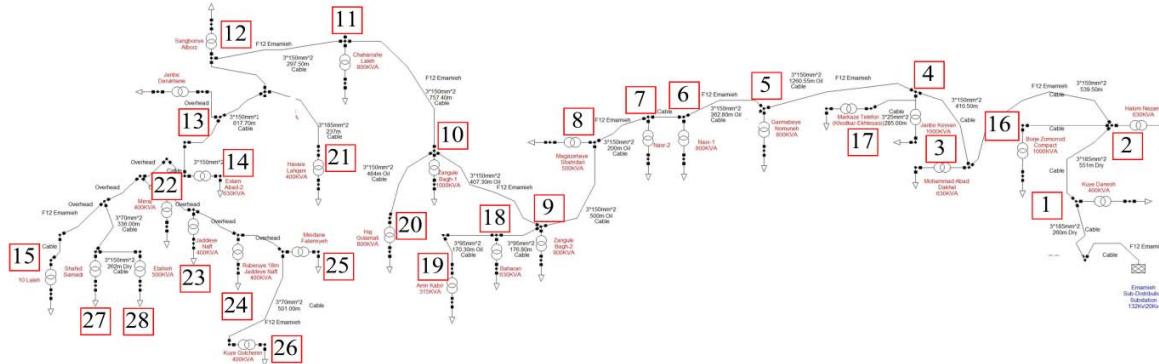
TABLE 2. TECHNICAL AND ECONOMIC DATA

| Parameters | Values | Parameters | Values |
|---|---|---|---|
| $V_i^{\max}$ (p.u.) | 1/05 | PF$_{DG}$ | 0/95 |
| $V_i^{\min}$ (p.u.) | 0/95 | $\rho^P$ ($/MWh) | 120 |
| $\lambda_{inv\&o}^{AM}$ ($/MWh) | 0/9 | $\rho^Q$ ($/Mvarh) | 95 |

### 4.3. Case Study: A Real 29-Bus Urban Network

Simulations on a 29-bus distribution network which is shown in Fig. 3 were performed and the objective function is determined. To better comparison, it is assumed that the locations of installed DGs at both cases (PM and AM) are identical. In comparing with the results of Table 3 and 4, we can conclude that by implementing active management programs, DG can have a greater impact on the power losses. In Table 4, a comparison between the decisions made by the DNO with the network operation in different modes has been provided. The results for passive and active networks are extracted and the benefit of the AM compared to the PM is obtained. According to the results of Table 4, by installing the DG units in the network, the network operator costs 3883.53 dollars are saved. This value will reach to 5798.72 dollar per day with implementing the AM programs. Benefit of active networks versus passive networks will be 1915.19 dollar per day. The first row of Table 4 shows that the properly installation of DG can reduce purchased energy from the grid. The last two rows show active and reactive power losses in the network for a daily period. Loss reduction in AM mode in comparison with PM will reach to 67 kWh per day. Table 5 shows optimal settings for RPCs and OLTC for each load level per day. The installed capacity of RPC1 and RPC2 are 0.5 and 3 MVAr. The purpose of this work is to make the proper conditions for operation of distribution network with the DG units. Network operation is smart, and there is a real-time control and management of the distribution network. These settings will be accordance with the voltage and reactive constraints.

Fig. 4 shows the voltage profiles for the three conventional, passive and active networks. The voltage curve is shown for the peak load (hour 22). According to Fig. 4, with distance from substations in the conventional networks, they will be faced with voltage drop. The proper installation of DG in system can improve the voltage profile. As Fig. 4, the voltage profiles for the AM and PM mode in peak hour have been located in permissible limits.



Fig.M_farsadi@yahoo.com 3. The single line diagram of urban system

TABLE 3. NETWORK DATA OF REAL 29-BUS URBAN NETWORK (DLF=1)

| Bus no | From | To | Length (km) | R (ohm) | X (ohm) | Capacity (kVA ) | $P_L$ (kW) | $Q_L$ (kvar) |
|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 1 | 0.260 | 0.0996 | 0.1287 | 400 | 90 | 45 |
| 2 | 1 | 2 | 0.550 | 0.2112 | 0.2721 | 630 | 290 | 140 |
| 3 | 2 | 3 | 0.540 | 0.2577 | 0.2754 | 630 | 370 | 180 |
| 4 | 3 | 4 | 0.410 | 0.1953 | 0.2091 | 1000 | 245 | 120 |
| 5 | 4 | 5 | 1.260 | 0.6009 | 0.6426 | 800 | 575 | 280 |
| 6 | 5 | 6 | 0.363 | 0.1731 | 0.1851 | 800 | 460 | 225 |
| 7 | 6 | 7 | 0.010 | 0.0477 | 0.0510 | 800 | 400 | 195 |
| 8 | 7 | 8 | 0.200 | 0.0954 | 0.1020 | 500 | 70 | 35 |
| 9 | 8 | 9 | 0.500 | 0.2385 | 0.2550 | 800 | 500 | 245 |
| 10 | 9 | 10 | 0.407 | 0.1941 | 0.2076 | 1000 | 615 | 300 |
| 11 | 10 | 11 | 0.757 | 0.3611 | 0.3861 | 800 | 380 | 185 |
| 12 | 11 | 12 | 0.297 | 0.1416 | 0.1515 | 250 | 200 | 100 |
| 13 | 12 | 13 | 0.210 | 0.1001 | 0.1071 | 630 | 315 | 155 |
| 14 | 13 | 14 | 0.618 | 0.2948 | 0.3152 | 630 | 440 | 215 |
| 15 | 14 | 15 | 1.440 | 2.600 | 1.572 | 500 | 250 | 125 |
| 16 | 2 | 16 | 0.100 | .04770 | 0.0510 | 500 | 300 | 145 |
| 17 | 4 | 17 | 0.285 | 0.7926 | 0.1188 | 250 | 200 | 100 |
| 18 | 9 | 18 | 0.177 | 0.1312 | 0.0945 | 630 | 320 | 155 |
| 19 | 18 | 19 | 0.340 | 0.2519 | 0.1816 | 315 | 70 | 35 |
| 20 | 10 | 20 | 0.484 | 0.2309 | 0.2468 | 800 | 415 | 205 |
| 21 | 13 | 21 | 0.237 | 0.0910 | 0.1173 | 400 | 125 | 65 |
| 22 | 14 | 22 | 0.530 | 0.9572 | 0.5788 | 400 | 235 | 115 |
| 23 | 22 | 23 | 0.270 | 0.4876 | 0.2948 | 400 | 120 | 60 |
| 24 | 23 | 24 | 0.280 | 0.5057 | 0.3057 | 400 | 160 | 80 |
| 25 | 24 | 25 | 0.260 | 0.4695 | 0.2839 | 400 | 245 | 120 |
| 26 | 25 | 26 | 0.501 | 0.5130 | 0.2775 | 400 | 270 | 130 |
| 27 | 14 | 27 | 0.980 | 1.770 | 1.070 | 500 | 250 | 125 |
| 28 | 27 | 28 | 0.262 | 0.1250 | 0.1336 | 500 | 190 | 95 |
| **Total** | | | | | | | 8100 | 3875 |

TABLE 4. THE RESULT OF ACTIVE LOSSES (KW) IN THREE OPERATION MODES AT EACH DAY

| Hour | Active management | Passive management | conventional operation | Hour | Active management | Passive management | Conventional operation |
|---|---|---|---|---|---|---|---|
| 1 | 0.051 | 0.095 | 0.175 | 13 | 0.050 | 0.090 | 0.167 |
| 2 | 0.047 | 0.050 | 0.096 | 14 | 0.050 | 0.092 | 0.170 |
| 3 | 0.050 | 0.036 | 0.068 | 15 | 0.056 | 0.112 | 0.202 |
| 4 | 0.052 | 0.032 | 0.058 | 16 | 0.056 | 0.107 | 0.195 |
| 5 | 0.052 | 0.033 | 0.060 | 17 | 0.053 | 0.101 | 0.184 |
| 6 | 0.052 | 0.032 | 0.057 | 18 | 0.055 | 0.106 | 0.193 |
| 7 | 0.050 | 0.038 | 0.071 | 19 | 0.056 | 0.111 | 0.201 |
| 8 | 0.050 | 0.038 | 0.072 | 20 | 0.056 | 0.123 | 0.219 |
| 9 | 0.048 | 0.047 | 0.090 | 21 | 0.062 | 0.167 | 0.287 |
| 10 | 0.048 | 0.066 | 0.126 | 22 | 0.070 | 0.200 | 0.334 |
| 11 | 0.047 | 0.078 | 0.146 | 23 | 0.064 | 0.176 | 0.299 |
| 12 | 0.048 | 0.078 | 0.147 | 24 | 0.059 | 0.147 | 0.256 |

TABLE 5. THE RESULTS NETWORK OPERATION FOR 29 BUS SYSTEM

| | Conventional management | Passive management | Active management | Benefit AM versus PM |
|---|---|---|---|---|
| Cost of grid purchased active and reactive power | 19742/51 | 11743/736 | 3678/632 | 8065 |
| Total cost ($/day) | 19742/51 | 15089/230 | 12958/160 | 2131 |
| $P_{loss}$ (kwh) | 3874 | 2156 | 1280 | 876 |
| $Q_{loss}$ (kwh) | 4270 | 2375 | 1049 | 1326 |

TABLE 6. OPTIMAL SETTING OLTC AND RPCs IN AM METHOD FOR 29-BUS URBAN NETWORK

| Hour | RPC$_1$ (Mvar) | RPC$_2$ (Mvar) | OLTC (p.u) | Hour | RPC$_1$ (Mvar) | RPC$_2$ (Mvar) | OLTC (p.u) |
|---|---|---|---|---|---|---|---|
| 1 | 0/500 | 1.843 | 1.026 | 13 | 0/500 | 1.788 | 1.026 |
| 2 | 0/500 | 1.171 | 1.021 | 14 | 0.500 | 1.807 | 1.026 |
| 3 | 0.500 | 0.869 | 1.018 | 15 | 0/500 | 2.000 | 1.028 |
| 4 | 0/500 | 0.756 | 1.004 | 16 | 0/500 | 1.994 | 1.027 |
| 5 | 0/500 | 0.774 | 1.009 | 17 | 0/500 | 1.918 | 1.027 |
| 6 | 0/500 | 0.750 | 0.950 | 18 | 0/500 | 1.995 | 0.952 |
| 7 | 0/018 | 1.390 | 0.975 | 19 | 0/500 | 2.000 | 1.028 |
| 8 | 0/500 | 0.910 | 1.019 | 20 | 0/500 | 2.000 | 1.030 |
| 9 | 0/500 | 1.107 | 1.020 | 21 | 0/500 | 2.000 | 1.037 |
| 10 | 0/500 | 1.448 | 1.023 | 22 | 0/500 | 2.000 | 1.041 |
| 11 | 0/179 | 1.950 | 0.951 | 23 | 0/500 | 2.000 | 1.038 |
| 12 | 0/500 | 1.626 | 1.024 | 24 | 0/500 | 2.000 | 1.034 |
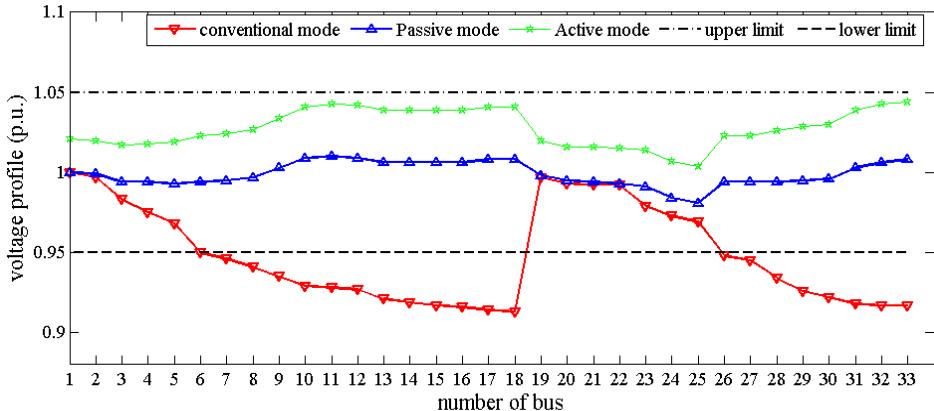


Fig. 4. Voltage profile for the different operation modes in peak hour

## 5. Conclusion

In this paper, active network management (ANM) has been presented to the distribution network operation along with the DG units which results maximum penetration of the DG and minimum cost of losses for DNOs. From studied results, it has been derived that voltage profile and loss of the network are intensely depends on management method of network. It has been shown that appropriate condition of operation has great effects on the DNO costs. Using active management has several benefits in comparison to passive management which cannot be neglected. These beneficial effects include reducing the active power loss. The ANM method also reduce the received power from the upstream network

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