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# Restoration in a Self-healing Distribution Network with DER and Flexible Loads

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***Abstract*—This paper develops an algorithm for energy management of a distribution network considering a restorative plan for most possible devastating contingencies in the network. The distribution network is self-healing and consists of smart meters and remotely-controlled automated switches. Distributed energy resources and flexible loads provide the redundant capacity for restoration. Under normal operating conditions, the objective of the energy management system is to minimize the generation cost, while under emergency conditions, the objective is to minimize the amount of shed load, giving priority to critical loads. The energy management problem forms a non-linear programming problem. Simulation results verify the effectiveness of the proposed algorithm in energy management and restoration of a distribution network.**

## I. INTRODUCTION

Negative social and economic impacts of service interruptions force the distribution network operators to reduce the frequency and duration of network outages. Grid upgrades and reinforcement can significantly reduce the frequency of outages, but cannot totally eliminate the risk of equipment failure, especially in distribution networks located in areas prone to natural disasters such as earthquakes and hurricanes. These events are subject to uncertainty [**?**], [**?**], [**?**] and they need to be properly modeled. Therefore, it is necessary for distribution network operators to be able to reduce the duration and severity of service interruptions once they occur. Under faulty conditions, protection devices identify the fault and isolate it from the rest of the distribution network. During switching operations for fault isolation, in addition to the faulty sections, some healthy sections of the network will also experience service interruption. The network operator needs to restore the service to these areas, in the shortest time possible.

Service restoration capability of a distribution network depends on two factors: the available capacity for restoration, and the speed of implementing the restoration plan. Traditionally, neighboring feeders have been responsible for providing the required capacity for restoration [**?**]. However, the integration of distributed energy resources (DER) including renewable energy resources into the network, and customers willing to participate in demand response programs have created new sources of flexibility capacity in the distribution network. This redundant capacity increases the flexibility and feasibility of restoration operation. In a smart self-healing distribution network with numerous smart meters capable of recording and reporting network data, and automated switches with remote control capability, service restoration can be faster and more effective. Smart meters can report data on the size and location of an outage, available flexibility capacity in the vicinity of outage area, and several other information useful for service restoration. On the other hand, remotely-controlled automated switches can implement the restoration plan without human intervention and increase the rapidity of service restoration. This paper develops an algorithm for service restoration in self-healing distribution networks with DER and flexible loads. The algorithm assumes two operating conditions for the distribution network: normal and emergency. The resiliency of a distribution network is defined with respect to its ability to withstand rare and extreme emergency events [**?**]. Distribution network operator cannot precisely predict when and where an outage may occur [**?**]. Hence, even under normal operating conditions, there must be a level of preparedness for emergency events such as component failures or natural disasters that may lead to service interruptions. Considering the topology of the network, historical data about previous outages, and the location of critical loads, the network operator can come up with worst case scenarios, and prepare a plan for service restoration in case the network enters an emergency state of operation. Under normal operation, the objective of distribution network operator is to supply the demand at minimum cost. However, when the network enters an emergency state, the objective will be maximizing the amount of restored loads, giving priority to critical loads. Under emergency operation, distribution network operator seeks alternative routes and energy resources to restore the service to outage areas. Alternative routes for power flow can be created through proper switching operations. In a self-healing network, the switching operations do not require human intervention, and hence network restoration is faster. Neighboring feeders, DER, and flexible loads can provide the required flexibility capacity for restoration.

The proposed algorithm considers most probable and most devastating contingency scenarios and includes them in the normal energy management of distribution network. The uncertainty of different scenarios is modeled using probabilistic approach [**?**]. This way, it ensures that the distribution network successfully restores as much critical load as possible in case of a contingency. Smart meters record and report information on the available capacity of distributed generation and the willingness of flexible loads to reduce their demand. The algorithm receives all the data from smart meters, and determines the normal scheduling of distribution network along with a restorative plan. The restorative plan follows the objective of minimizing the amount of shed load (interchangeably, maximizing restored load) considering technical constraints such as network topology, branch flow limits,availability of DER and comfort level of flexible loads. The energy management problem considering restorative actions forms a non-linear programming problem that commercial packages can solve.

The main contributions of this work are first combining normal and emergency operations of a distribution network in one optimization problem, and second, considering the role of demand flexibility and DER in service restoration. We analyze the performance of proposed algorithm for different case studies on IEEE 33-bus system as the test distribution network. Simulation results show the algorithm can successfully restore the service to outage areas in each case study.

## II. Problem formulation

Under normal operating conditions, the objective is to minimize generation cost, $(OF_n)$

$$\min OF_n = \sum_{i=1}^{N} J_i\left(P_i^g\right), \tag{1}$$

subject to the following technical constraints:

Active/Reactive power balance:

$$P_i^g - P_i^d = \tag{2}$$
$$\sum_{j=1}^{N} V_i V_j \left(G_{ij}\cos\left(\delta_{ij}\right) + B_{ij}\sin\left(\delta_{ij}\right)\right)$$
$$Q_i^g - Q_i^d = \tag{3}$$
$$\sum_{j=1}^{N} V_i V_j \left(G_{ij}\sin\left(\delta_{ij}\right) - B_{ij}\cos\left(\delta_{ij}\right)\right)$$
$$\delta_{ij} = \delta_i - \delta_j \tag{4}$$

Branches flow limits:

$$|S_{ij}| \leq S_{ij}^{max} \tag{5}$$

Voltage limits:

$$V_i^{min} \leq V_i \leq V_i^{max} \tag{6}$$

Generation limits:

$$P_i^{g,min} \leq P_i^g \leq P_i^{g,max} \tag{7}$$
$$Q_i^{g,min} \leq Q_i^g \leq Q_i^{g,max} \tag{8}$$

where:
$P/Q_i^g$: Active/reactive power generation at node $i$.
$P/Q_i^d$: Total active/reactive load at node $i$.
$S_{ij}$: Branch $ij$ flow.
$V_i$: Voltage magnitude at node $i$.
$\delta_i$: Voltage phase angle at node $i$.
$G_{ij}$: Conductance matrix which is the real part of network's $Y_{bus}$ matrix.
$B_{ij}$: Susceptance matrix which is the imaginary part of network's $Y_{bus}$ matrix.
$J_i(.)$: Generation cost function at node $i$ which is a quadratic function: $J_i\left(P_i^g\right) = a_i {P_i^g}^2 + b_i P_i^g + c_i$.

When a contingency occurs in the distribution network, the objective is to minimize the amount of load shedding and generation cost, with priority given to load shedding minimization. Therefore:

$$\min OF_c = \lambda \sum_{s=1}^{\Omega_S} \pi_s \tau_s \sum_{i=1}^{N} w_i P_{s,i}^{ls} \tag{9}$$

Under emergency conditions, the technical constraints change accordingly:
Active/Reactive power balance:

$$P_{s,i}^g - P_{s,i}^d + P_{s,i}^{ls} = \tag{10}$$
$$\sum_{j=1}^{N} V_{s,i} V_{s,j} \left(G_{ij}\cos\left(\delta_{s,ij}\right) + B_{ij}\sin\left(\delta_{s,ij}\right)\right)$$
$$Q_{s,i}^g - Q_{s,i}^d + Q_{s,i}^{ls} = \tag{11}$$
$$\sum_{j=1}^{N} V_{s,i} V_{s,j} \left(G_{ij}\sin\left(\delta_{s,ij}\right) - B_{ij}\cos\left(\delta_{s,ij}\right)\right)$$
$$\delta_{s,ij} = \delta_{s,i} - \delta_{s,j} \tag{12}$$

Branches flow limits:

$$|S_{s,ij}| \leq (1 - u_{s,i} u_{s,j} \gamma_{s,ij})\, S_{ij}^{max} \tag{13}$$

Voltage limits:

$$V_i^{min} \leq V_{s,i} \leq V_i^{max} \tag{14}$$

Generation limits:

$$P_i^{g,min} \leq P_{s,i}^{g} \leq (1 - u_{s,i} \kappa_{s,i})\, P_i^{g,max} \tag{15}$$

$$Q_i^{g,min} \leq Q_{s,i}^{g} \leq (1 - u_{s,i} \kappa_{s,i})\, Q_i^{g,max} \tag{16}$$

Flexible load limits:

$$0 \leq P_{s,i}^{ls} \leq \bar{P}_{s,i}^{d} \tag{17}$$

$$0 \leq Q_{s,i}^{ls} \leq \bar{Q}_{s,i}^{d} \tag{18}$$

where:

$P/Q_{s,i}^{g}$: Active/reactive power generation at node $i$ in scenario $s$.

$P/Q_{s,i}^{d}$: Total active/reactive load at node $i$ in scenario $s$.

$P/Q_{s,i}^{ls}$: Total active/reactive load shed at node $i$ in scenario $s$.

$V_{s,i}$: Voltage magnitude at node $i$ in scenario $s$.

$\delta_{s,i}$: Voltage phase angle at node $i$ in scenario $s$.

$S_{s,ij}$: Branch $ij$ flow in scenario $s$.

$w_i$: Load priority weighting factor at node $i$.

$\lambda$: Load shedding penalty factor.

$u_{s,i}$: A binary parameter to show if the contingency has affected node $i$; 1: affected 0: not affected

$\gamma_{s,ij}$: Percent reduction in distribution capacity of branch $ij$ in scenario $s$. Note that a branch is affected only if both its sending and receiving ends are involved.

$\kappa_{s,i}$: Percent reduction in generation capacity of node $i$ (if any DER is connected to the node) in scenario $s$. Note that if node 1 is involved, substation generation capacity will decrease by $\kappa_{s,1}\%$.

The energy management system minimize the overall objective, $OF$, which is comprised of total costs in normal and contingency conditions:

$$OF = OF_n + OF_c \tag{19}$$

## III. SIMULATION RESULTS

In this section, we conduct two case studies to compare the performance of proposed automated self-healing plan with an operator-dependent semi-manual restorative procedure. Our test system is IEEE 33-bus test feeder shown in Figure **??**. We modify the system to add DER and flexible demand to it. Also, we assume that the distribution feeder is located in an area prone to natural disasters. Simulation assumptions are as followed:

- DER penetration is 34.6% of feeder's total apparent power. Table **??** shows the capacity of each DER.

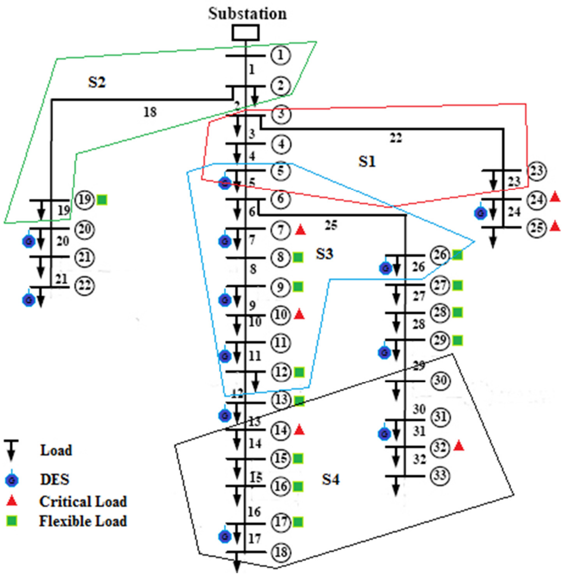

Fig. 1. IEEE 33-bus test feeder

- Generation cost function coefficients ($a_i$, $b_i$ and $c_i$ ) at each DER bus as well as the substation are according to Table **??**.
- Loads are divided into three categories: Non-critical non-flexible, non-critical flexible, and critical. Table **??** shows the weighting factor for each critical load.
- Natural disasters tend to affect the upstream feeder more than downstream feeder [**?**].
- We identify four most probable contingency scenarios, $S_1$, $S_2$, $S_3$, and $S_4$. Table **??** shows the characteristics of each scenario. If the disaster affects a bus, DER connected to it cannot generate any power ($\kappa_{s,i} = 100\%$). Also the capacities of all distribution branches in an affected area decrease by the same factor (same $\gamma_{s,ij}$ for all affected branches). In scenario II, node 1 and the substation are involved, and the substation capacity decreases by 70%.

TABLE I
DER CONNECTION POINTS AND THEIR CAPACITIES

| | | |
|---|---|---|
| DER | Location | 5, 7, 9, 11, 13, 17, 20, 22, 24<br>26, 29, 31 |
| | Capacity [kW] | 67, 224, 63, 54, 69, 63, 98, 98, 47<br>65, 139, 166 |
| Critical Loads | Location | 7, 10, 14 ,24, 25, 32 |
| | $w_i$-factor | 0.06, 0.07, 0.1, 0.20, 0.15, 0.20 |

### A. *Semi-manual Restoration*

In the first case study, we assume that following each contingency, a human operator takes corrective actions to restore the service in affected areas. The operator runs a simple optimization program to determine what

TABLE II

COST COEFFICIENTS OF GENERATING UNITS

| Bus | 5,7,9 | 11,13,17 | 20,22,24 | 26,29 | 31 | Sub |
|---|---|---|---|---|---|---|
| $a_i$[\$/MWh$^2$] | 0.04 | 0.015 | 0.035 | 0.04 | 0.03 | 0.02 |
| $b_i$[\$/MWh] | 4 | 1.5 | 3.5 | 4 | 3 | 2 |
| $c_i$[\$] | 0 | 0 | 0 | 0 | 0 | 0 |

TABLE III

CONTINGENCY SCENARIOS

| Scenario | Bus | $\kappa_{s,sub}$ [%] | $\kappa_{s,i}$ [%] | $\gamma_{s,ij}$ [%] | $\pi_s$ | $\tau_s$ [h] |
|---|---|---|---|---|---|---|
| $S_1$ | 3-5, 23 | 0 | 100 | 70 | 0.4 | 8 |
| $S_2$ | 1,2,19 | 70 | 100 | 70 | 0.3 | 4 |
| $S_3$ | 5-12,26 | 0 | 100 | 60 | 0.2 | 10 |
| $S_4$ | 14-18, 30-33 | 0 | 100 | 80 | 0.1 | 8 |

corrective actions to take. The objective of optimization program is to minimize load shedding cost, subject to system technical constraints. Compared to the automated self-healing restoration plan, the semi-manual plan:

- forces DER to operate at unity power factor, and
- does not distinguish between non-critical non-flexible and non-critical flexible loads, and hence assumes the same weighting factors for all non-critical loads (that is 0.008148).

Since contingencies are not anticipated, the operator has to take the most appropriate actions on very short notice. Hence the restorative algorithm must be as simple as possible. This justifies the assumptions we have made regarding the semi-manual restoration procedure.

Table **??** shows the corrective actions the operator has taken in each scenario. The last column of the Table shows the restoration cost for each scenario. The second scenario, $S_2$ which affects buses 1,2 and 19, as well as the substation, is the most disastrous contingency and requires a significant amount of load shedding. Considering the probability of each scenario, total restoration cost in the semi-manual case will be \$31.

### B. Automated Self-healing Restoration

In the second case study, we assume that the distribution network is self-healing, and in case of emergency, uses the automated restoration plan augmented in its energy management system. Table **??** shows the system dispatch under normal operating conditions. The Generation cost is \$8.2.

The energy management system considers contingency scenarios, $S_1$, $S_2$, $S_3$, and $S_4$ even when the system is operating under normal conditions. This adds a level of preparedness to the system. The automated self-healing restoration plan:

- allows DER to change their power factors between 0.9 to 1 (lagging or leading), and
- assumes that non-critical non-flexible have weighting factors of 0.01, while non-critical flexible loads have weighting factors of 0.005.

TABLE IV

SIMULATION RESULTS FOR THE SEMI-MANUAL RESTORATION PLAN

| Gen. | $S_1$ | | $S_2$ | | $S_3$ | | $S_4$ | |
|---|---|---|---|---|---|---|---|---|
| | P | Q | P | Q | P | Q | P | Q |
| DER | kW | kVar | kw | kVar | kW | kVar | kW | kVar |
| 5 | 0 | 0 | 67 | 0 | 0 | 0 | 41 | 0 |
| 7 | 224 | 0 | 22 | 0 | 0 | 0 | 181 | 0 |
| 9 | 63 | 0 | 63 | 0 | 0 | 0 | 44 | 0 |
| 11 | 54 | 0 | 54 | 0 | 0 | 0 | 37 | 0 |
| 13 | 70 | 0 | 70 | 0 | 70 | 0 | 52 | 0 |
| 17 | 63 | 0 | 63 | 0 | 63 | 0 | 0 | 0 |
| 20 | 99 | 0 | 99 | 0 | 99 | 0 | 55 | 0 |
| 22 | 99 | 0 | 99 | 0 | 99 | 0 | 55 | 0 |
| 24 | 465 | 0 | 465 | 0 | 465 | 0 | 386 | 0 |
| 26 | 65 | 0 | 65 | 0 | 0 | 0 | 42 | 0 |
| 29 | 139 | 0 | 139 | 0 | 139 | 0 | 109 | 0 |
| 31 | 166 | 0 | 166 | 0 | 166 | 0 | 0 | 0 |
| Sub | 1680 | 1496 | 656 | 1005 | 2624 | 2088 | 2839 | 2394 |
| LS | | | | | | | | |
| 2 | 0 | 0 | 100 | 60 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 90 | 40 | 0 | 0 | 0 | 0 |
| 4 | 96 | 64 | 120 | 80 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 60 | 30 | 0 | 0 | 0 | 0 |
| 8 | 0 | 0 | 200 | 100 | 0 | 0 | 0 | 0 |
| 11 | 45 | 30 | 45 | 30 | 0 | 0 | 0 | 0 |
| 12 | 60 | 35 | 60 | 35 | 0 | 0 | 0 | 0 |
| 13 | 60 | 35 | 60 | 35 | 0 | 0 | 0 | 0 |
| 18 | 0 | 0 | 90 | 40 | 0 | 0 | 0 | 0 |
| 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 21 | 0 | 0 | 46 | 20 | 0 | 0 | 0 | 0 |
| 22 | 0 | 0 | 8 | 3 | 0 | 0 | 0 | 0 |
| 23 | 47 | 26 | 90 | 50 | 0 | 0 | 0 | 0 |
| 26 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 27 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 29 | 0 | 0 | 120 | 70 | 0 | 0 | 0 | 0 |
| 30 | 200 | 600 | 200 | 600 | 94 | 282 | 0 | 0 |
| 31 | 0 | 0 | 150 | 70 | 0 | 0 | 0 | 0 |
| 33 | 60 | 40 | 60 | 40 | 0 | 0 | 0 | 0 |
| ΣLS | 568 | 830 | 1499 | 1304 | 94 | 282 | 0 | 0 |
| Σ **Cost [\$]** | 37 | | 48.8 | | 7.7 | | 0 | |

TABLE V

SYSTEM DISPATCH UNDER NORMAL CONDITIONS

| Bus | 5,7,9 | 11 | 13 | 17 | 20,22 | 24 | 26,29 | 31 | Sub |
|---|---|---|---|---|---|---|---|---|---|
| P [kW] | 0 | 26 | 34 | 31 | 0 | 61 | 0 | 80 | 3368 |
| Q [kVar] | 0 | 54 | 69 | 63 | 0 | 126 | 0 | 166 | 2157 |

Table **??** shows how the self-healing network restores power in affected areas. If we compare this Table to Table **??**, we can see that the total amount of shed load and restoration costs are much lower in the self-healing network which uses the proposed automated restoration plan. Considering the probabilities of scenarios, total restoration cost in this case will be \$17, which is much lower than that of semi-manual case.

## IV. CONCLUSION

This paper proposes an automated restoration algorithm to be integrated in the energy management system of a self-healing distribution network which contains DER and flexible loads. Under normal operating conditions, the energy management system minimizes the generation cost, while under emergency conditions it minimizes the amount of load shed. The algorithm considers the most probable and most devastating contingencies that may occur in the network. Moreover, the algorithm is flexible in terms of allowing generation units to control their reactive power, and

TABLE VI
SIMULATION RESULTS FOR THE AUTOMATED SELF-HEALING PLAN

| Gen. | $S_1$ | | $S_2$ | | $S_3$ | | $S_4$ | |
|---|---|---|---|---|---|---|---|---|
| | P | Q | P | Q | P | Q | P | Q |
| DER | kW | kVar | kw | kVar | kW | kVar | kW | kVar |
| 5 | 0 | 0 | 67 | 32 | 0 | 0 | 0 | 0 |
| 7 | 224 | 108 | 224 | 108 | 0 | 0 | 0 | 0 |
| 9 | 63 | 31 | 63 | 31 | 0 | 0 | 0 | 0 |
| 11 | 54 | 26 | 54 | 26 | 0 | 0 | 54 | 0 |
| 13 | 69 | 34 | 69 | 34 | 69 | 34 | 69 | 26 |
| 17 | 63 | 31 | 63 | 31 | 63 | 31 | 0 | 34 |
| 20 | 0 | 0 | 98 | 48 | 0 | 0 | 0 | 0 |
| 22 | 0 | 0 | 98 | 48 | 0 | 0 | 0 | 0 |
| 24 | 394 | 190 | 465 | 225 | 0 | 0 | 379 | 0 |
| 26 | 65 | 31 | 65 | 31 | 0 | 0 | 0 | 183 |
| 29 | 139 | 67 | 139 | 67 | 139 | 67 | 0 | 0 |
| 31 | 166 | 80 | 166 | 80 | 166 | 80 | 0 | 0 |
| Sub | 2130 | 1152 | 1036 | 606 | 3316 | 2078 | 3366 | 2162 |
| LS | | | | | | | | |
| 8 | 0 | 0 | 200 | 100 | 0 | 0 | 0 | 0 |
| 9 | 0 | 0 | 60 | 20 | 0 | 0 | 0 | 0 |
| 12 | 60 | 35 | 60 | 35 | 0 | 0 | 0 | 0 |
| 13 | 60 | 35 | 60 | 35 | 0 | 0 | 0 | 0 |
| 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16 | 0 | 0 | 60 | 20 | 0 | 0 | 0 | 0 |
| 17 | 0 | 0 | 60 | 20 | 0 | 0 | 0 | 0 |
| 19 | 0 | 0 | 90 | 40 | 0 | 0 | 0 | 0 |
| 26 | 0 | 0 | 60 | 25 | 0 | 0 | 0 | 0 |
| 27 | 0 | 0 | 60 | 25 | 0 | 0 | 0 | 0 |
| 28 | 0 | 0 | 50 | 17 | 0 | 0 | 0 | 0 |
| 29 | 61 | 36 | 120 | 70 | 0 | 0 | 0 | 0 |
| 30 | 174 | 521 | 200 | 600 | 45 | 134 | 0 | 0 |
| Σ LS | 355 | 627 | 1080 | 1007 | 45 | 134 | 0 | 0 |
| Σ **Cost [$]** | 21.1 | | 25.6 | | 4.7 | | 0 | |

using flexible load to provide restoration capacity. Simulation results showed that compared to a less flexible semi-manual plan, the automated self-healing plan has a considerably less restoration cost.

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## REFERENCES

[1] A. Soroudi, P. Siano, and A. Keane, "Optimal DR and ESS scheduling for distribution losses payments minimization under electricity price uncertainty," *IEEE Transactions on Smart Grid*, vol. 7, no. 1, pp. 261–272, Jan 2016.

[2] C. Murphy, A. Soroudi, and A. Keane, "Information gap decision theory-based congestion and voltage management in the presence of uncertain wind power," *IEEE Transactions on Sustainable Energy*, vol. 7, no. 2, pp. 841–849, April 2016.

[3] P. Maghouli, A. Soroudi, and A. Keane, "Robust computational framework for mid-term techno-economical assessment of energy storage," *IET Generation, Transmission Distribution*, vol. 10, no. 3, pp. 822–831, 2016.

[4] B. Ansari and S. Mohagheghi, "Electric service restoration using microgrids," in *2014 IEEE PES General Meeting — Conference Exposition*, July 2014, pp. 1–5.

[5] M. Olken, "The resiliency of the grid: Putting the plans in place [from the editor]," *IEEE Power and Energy Magazine*, vol. 13, no. 3, pp. 4–4, May 2015.

[6] A. Soroudi and T. Amraee, "Decision making under uncertainty in energy systems: State of the art," *Renewable and Sustainable Energy Reviews*, vol. 28, pp. 376 – 384, 2013.

[7] A. Soroudi, "Possibilistic-scenario model for dg impact assessment on distribution networks in an uncertain environment," *IEEE Transactions on Power Systems,*, vol. PP, no. 99, p. 1, 2012.

[8] B. Ansari and S. Mohagheghi, "Optimal energy dispatch of the power distribution network during the course of a progressing wildfire," *International Transactions on Electrical Energy Systems*, vol. 25, no. 12, pp. 3422–3438, 2015.