

Reconfiguration of Power Distribution Networks

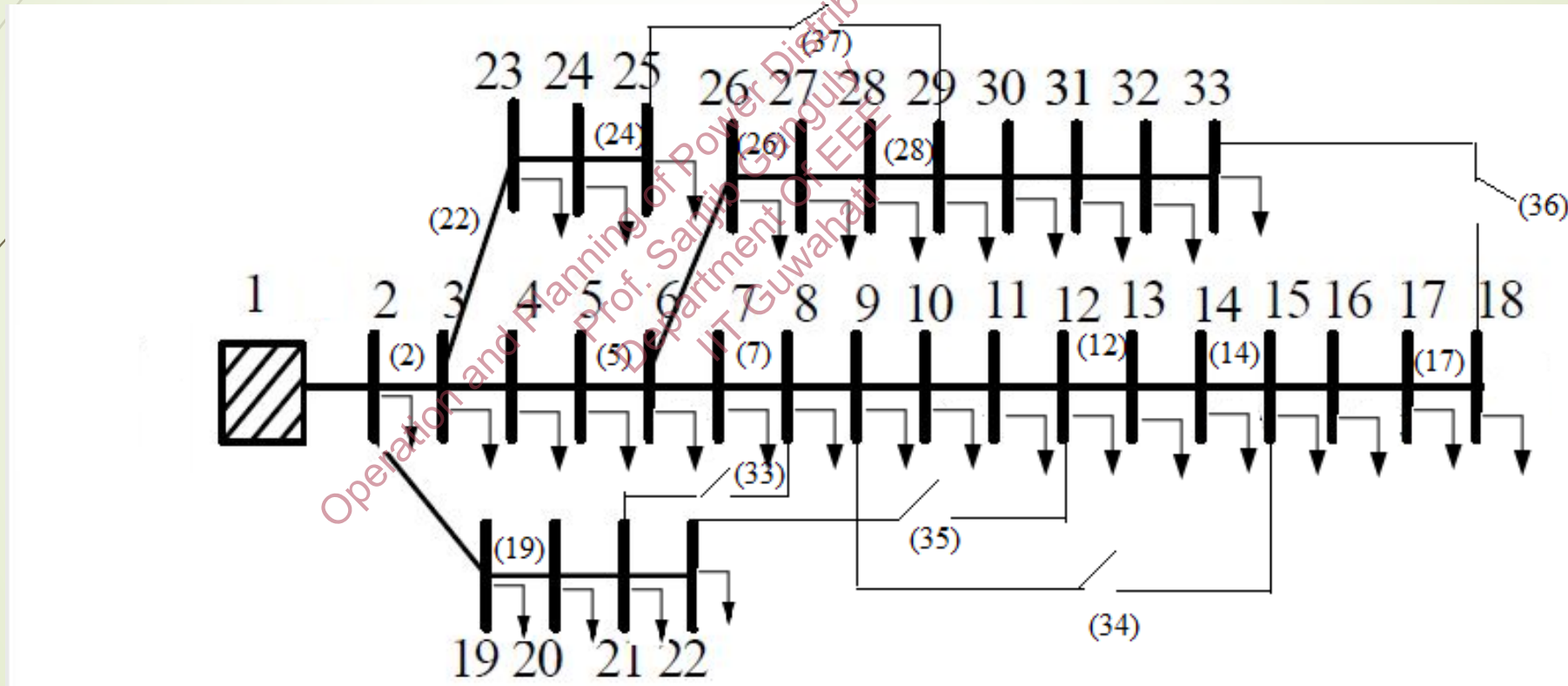
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What is reconfiguration?

- Reconfiguration is to change the topology of a network.
- Configurations may be varied with manual or automatic switching operations.
- The change in the network configuration is performed by opening sectionalizing (normally closed) and closing tie (normally open) switches of the network.
- All the demands shall be met during reconfiguration.
- The radiality of the network shall be maintained.

33-bus network with normally open switches



Benefits obtained from reconfiguration

- The **optimal network reconfiguration** provides the following benefits:
 - power loss reduction
 - improvement in bus voltage
 - improvement in network reliability
 - increase system security

Network Reconfiguration Problem

- ❑ Power Distribution Network Reconfiguration: An optimization problem.
- ❑ The problem can be either single objective or multi-objective.
- ❑ Challenges of Network Reconfiguration Problem:
 - ✓ Extremely large combinatorial solution space
 - ✓ Requirement of a very fast loss estimation technique for repeated and continuous evaluation of each these configurations.
- ❑ Motivations behind the research on Network Reconfiguration Problem:
 - ✓ the gradual emergence of smart distribution systems with growing penetration of distributed generators (DGs) and modern FACTS devices, advance applications of information and communication techniques (ITC), availability of new meta-heuristic optimization techniques and growing stochastic environment

Optimization Objectives and Constraints

Objectives

- Maximization of service restoration
- Energy loss minimization
- Feeder load balancing or transformer load balancing
- Prevention of transformer and feeder overloading
- Minimizing switching cost and number of switching
- Maximization of voltage stability index

Optimization Objectives and Constraints

Constraints

- Power balance
- Bus voltage
- Thermal limit of line
- Radiality
- Distributed generation constraints, if any

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Optimization Objectives and Constraints

Examples of Single objective optimization problems

➤ *Minimization of energy loss:* $\min \sum_{b=1}^{N_{br}} |I_b|^2 R_b K_b$

where, N_{br} is the number of closed branches. R_b , I_b and K_b are resistance, the current and topological status of the closed branch respectively.

➤ *Minimization financial losses due to voltage sags* $\min |\sum_{b=1}^{N_b} f P_c P_f C|$

where f is the frequency of voltage sags at a particular node; P_c is the probability of a particular load composition at the node; P_f is the probability of equipment/process failure; C is the cost associated with the tripping of the equipment/process and N_b is the number of buses of interest.

Optimization Objectives and Constraints

Examples of multi-objective optimization problems

- Minimize power loss, worst voltage drop, service interruption frequency, transformer load balancing and balanced service of important customers.
- Minimize power loss along with Expected Energy Not Supplied, System Average Interruption Frequency Index, System Average Interruption Duration Index and Average Service Availability Index.
- Minimize Power Loss and number of interrupted customers per year subject to voltage, current and radiality constraints
- Minimize a cost function defined and energy not supplied
- Minimize operating costs by minimizing real and reactive power loss along with maximizing operating reliability by minimizing total interruption cost with usual voltage constraints

Optimization Approaches Used in Multi-objective problems

- Weighted sum multi-objective approach
- Fuzzy multi-objective approach
- Pareto-based multi-objective approach

Optimization Approaches Used in Multi-objective problems

Weighted sum multi-objective approach

► Examples:

► $\min f = w_1 PL + w_2 EENS + w_3 SAIFI + w_4 SAIDI + w_5 ASAI$

► $\min f = w_1 PL + w_2 TLB + w_3 WVD + w_4 SIF + w_5 BSIC$

where, PL: power loss; EENS: Expected Energy Not Supplied; SAIFI: System Average Interruption Frequency Index; SAIDI: System Average Interruption Duration Index; ASAI: Average Service Availability Index; WVD: worst voltage drop; SIF: service interruption frequency; TLB: Transformer Load Balancing and BSIC: balanced service of important customers.

Optimization Approaches Used in Multi-objective problems

Fuzzy multi-objective approach

When several objectives are simultaneously considered for optimization, it is preferred to go for optimization with soft limits (rather than hard limits) in terms of fuzzy membership values, the approach popularly known as fuzzy multi-objective.

$$\text{Max } f = w_1\mu_P + w_2 \sum_{i=1}^{nb} \mu_{Vi} + w_3 \sum_{i=1}^{nbr} \mu_{ii} + w_4\mu_S$$

Where, μ_P , μ_{Vi} , μ_{ii} , μ_S are the membership values to minimize the power loss, sum of membership values to minimize the bus voltage deviations, sum of membership values to minimize the current violation, and number of switching respectively.

Optimization Approaches Used in Multi-objective problems

Pareto-based multi-objective approach

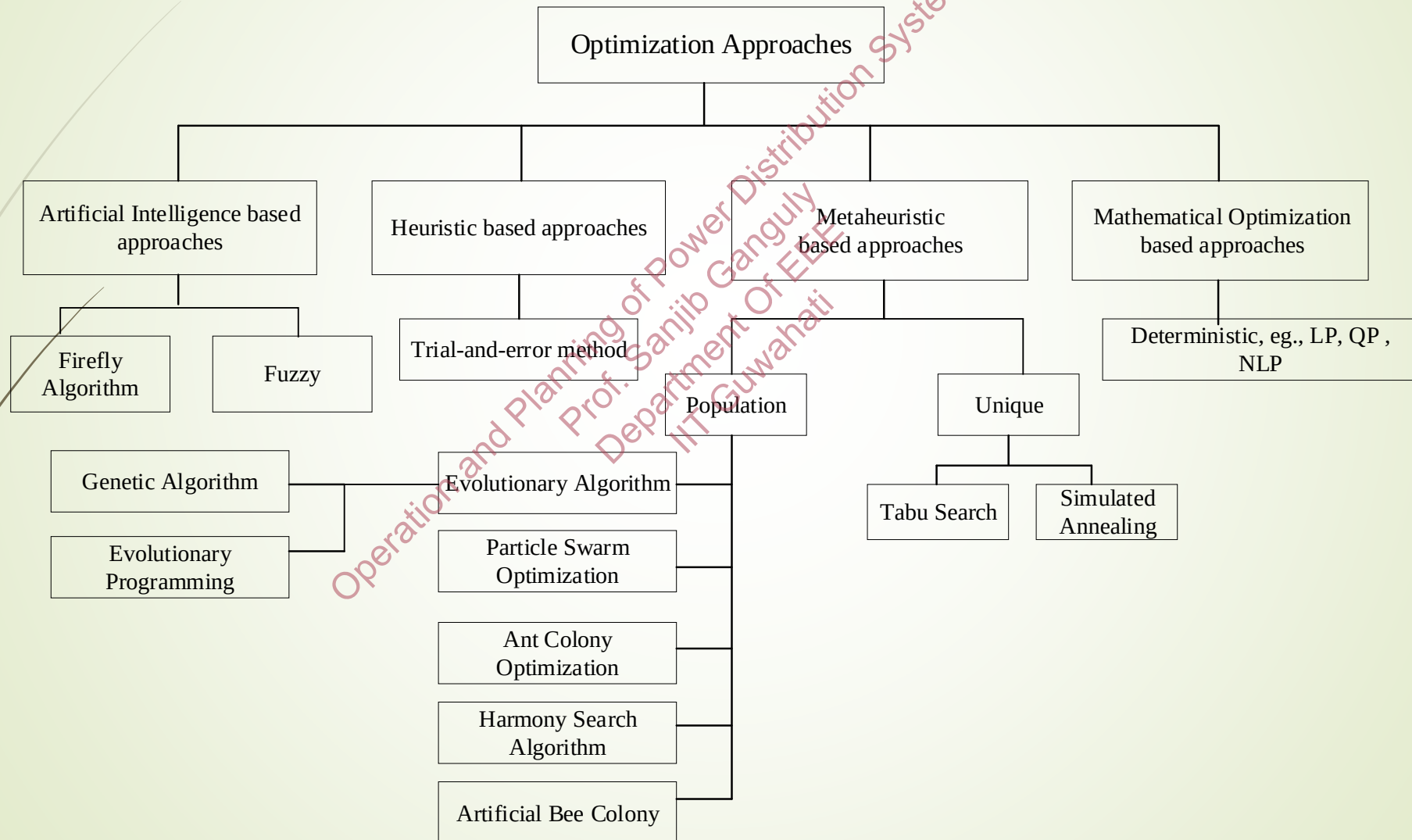
- Conflicting type of objectives formulation, i.e., Cost, reliability, and power quality based objectives
- In such situations, better values for all the individual objectives do not exist.
- Non-dominant solutions having best possible trade-off among objectives are preferred.
- The set of such solutions is known as Pareto front

Classification of Optimization Approaches

Power Distribution Network Reconfiguration methods are broadly classified into three categories:

- Heuristics
- Metaheuristic
- Mathematical optimization based approaches
- Hybrid methods

Optimization Approaches



Basic Algorithm for Reconfiguration Process

Begin

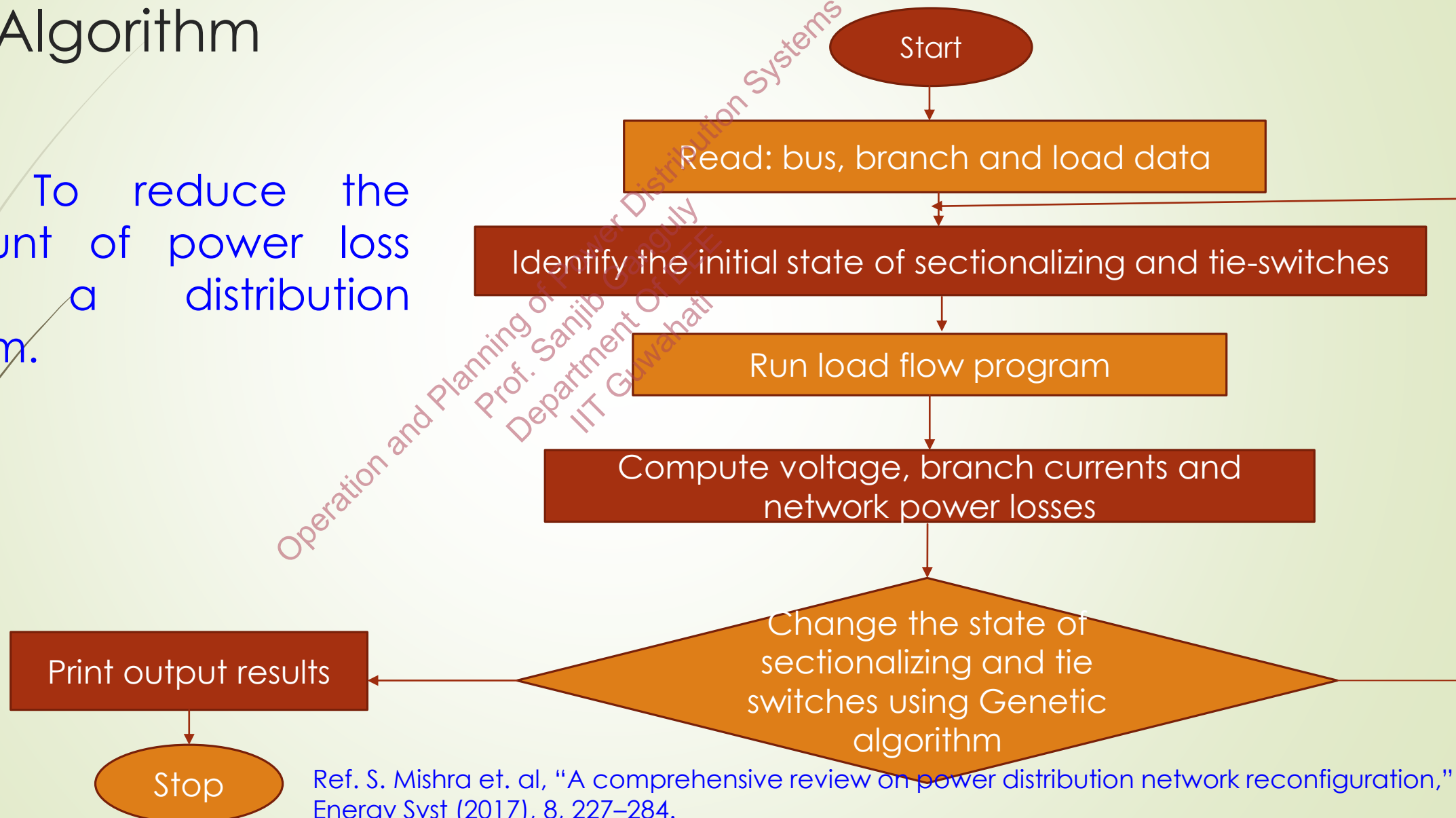
- Step 1: Read: Network and Switch Data
- Step 2: Close all normally open switches → Meshed Network Formation
- Step 3: Convert loads to nodal current injections and run the power flow for the resulting network.
- Step 4: Determine the optimal power flow pattern of the network
- Step 5: Open the switch carrying the lowest current as determined from the optimal power flow pattern
- Step 6: Close the last switch opened. Open the switch carrying the next lowest current as determined by the optimal flow pattern
- Step 7: Is there any constraint violation?
- Step 8: If yes, repeat step 6
- Step 9: If no, Then is it radial network?
- Step 10: If yes, print the results
- Step 11: If no, proceed to step 3 and step 4 and repeat the steps.

End

Ref. Shirmohammadi, D., Hong, H.W.: Reconfiguration of electric distribution on networks for resistive line loss reduction. IEEE Trans. Power Deliv. 4(1), 1492–1498 (1989)

An Illustration on Reconfiguration using Genetic Algorithm

- Aim: To reduce the amount of power loss from a distribution system.

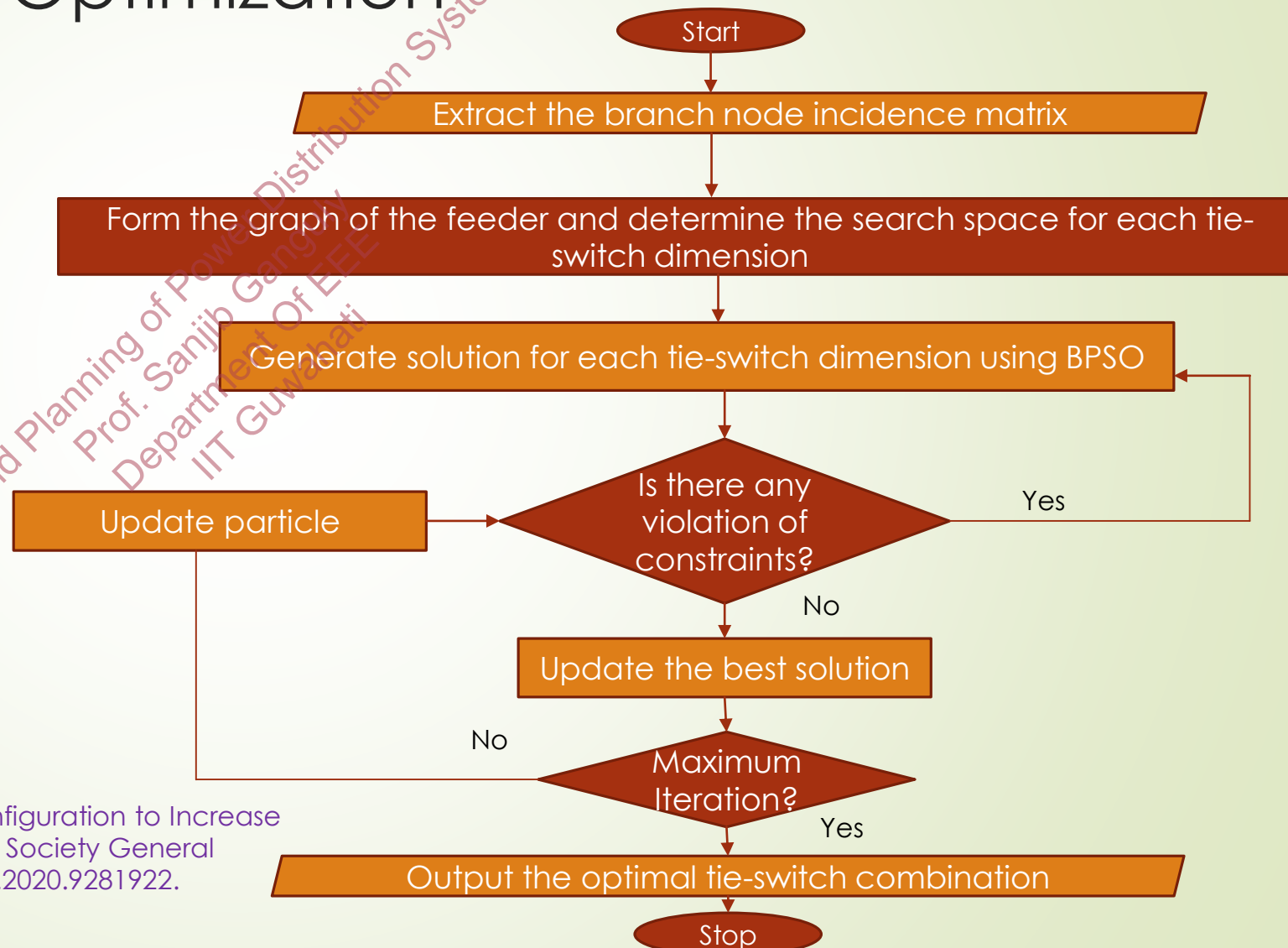


An Illustration on Reconfiguration using Binary Particle Swarm Optimization

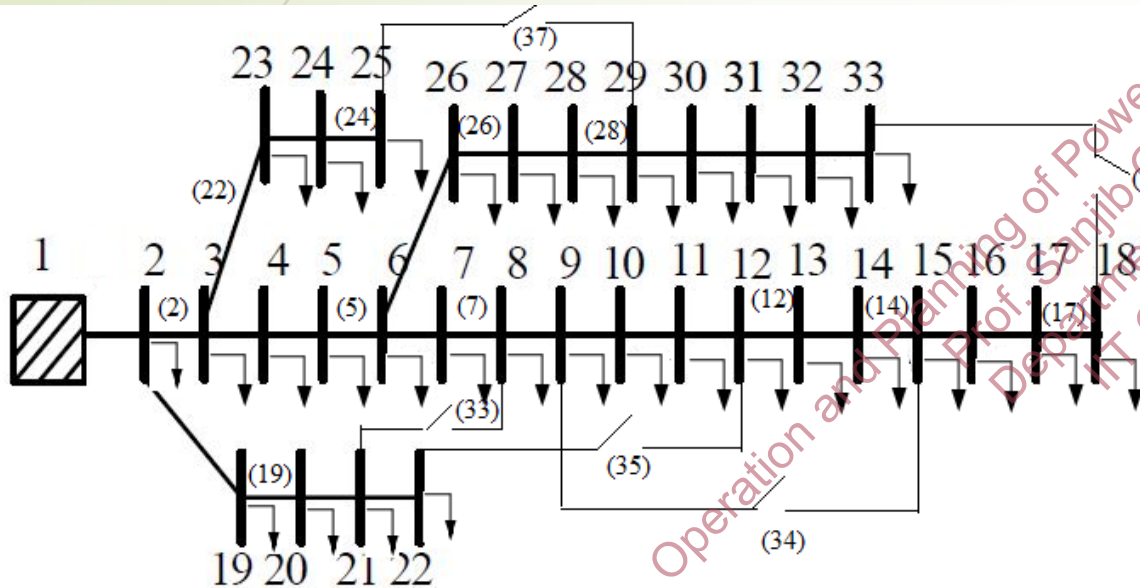
Aim: To increase the PV hosting capacity

The PV Hosting Capacity of a distribution feeder is defined as the maximum amount of PV that can be accommodated without adversely affecting the network performance during operation.

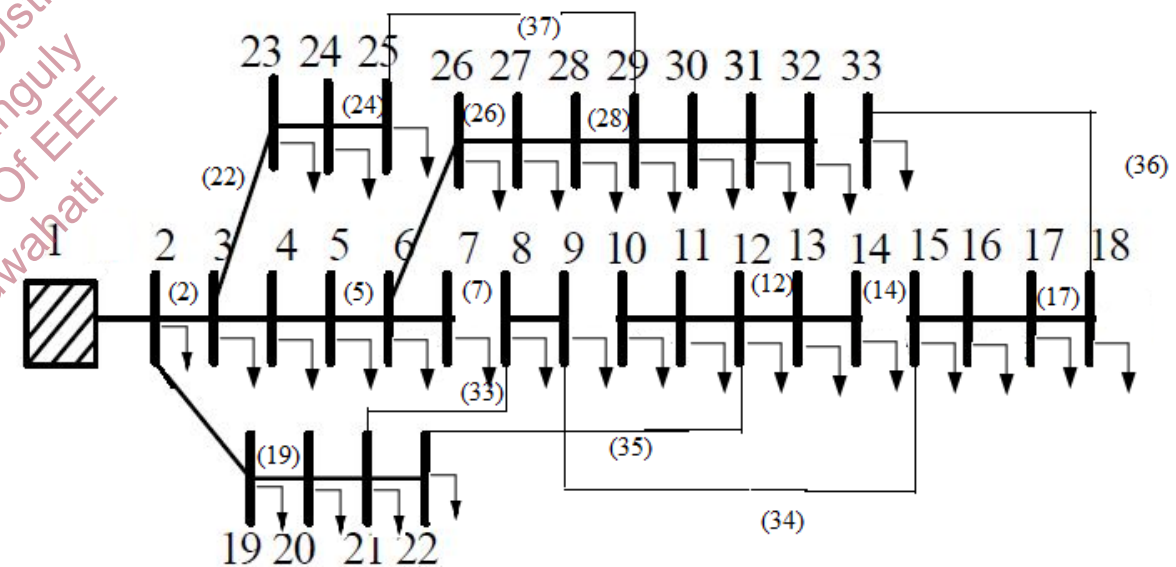
Ref. Roshni Anna Jacob et. al, "Distribution Network Reconfiguration to Increase Photovoltaic Hosting Capacity," 2020 IEEE Power & Energy Society General Meeting (PESGM), 2020, pp. 1-5, doi: 10.1109/PESGM41954.2020.9281922.



33-bus network before and after Reconfiguration



Before Reconfiguration



After Reconfiguration

Ref. S. Mishra et. al, "A comprehensive review on power distribution network reconfiguration," Energy Syst (2017), 8, 227–284.

Results of 33-bus network

Before Reconfiguration		After Reconfiguration	
Initial Power Loss (kW)	Minimum Voltage (p.u)	Final Power Loss (kW)	Final open branches
202.68	0.9131	136.57	7,9,14, 32, 37

Reconfiguration Problem in Stochastic Environment: A new challenge

- Increased penetration of solar photovoltaics, wind turbine, plug-in-electric vehicles
- Techniques to handle uncertainties: Monte Carlo simulation method, analytical method, approximate methods

Future Research Directions of Reconfiguration

- To enhance network voltage stability and maximize the utilization of DG
- To find the optimal distribution network operation by taking into account dynamic loads and DG operation modes
- To develop an algorithm that is suitable for real-time network reconfiguration.
- To develop network reconfiguration strategy with voltage control, which could be the capacitor bank, battery storage, or voltage regulator.
- To improve the operational performance of the Smart Distribution Network by developing the detailed mode scheduling and transfer schemes.

- Shirmohammadi, D., Hong, H.W.: Reconfiguration of electric distribution on networks for resistive line loss reduction. IEEE Trans. Power Deliv. 4(1), 1492–1498 (1989)
- Ola Badran et. al, “Optimal reconfiguration of distribution system connected with distributed generations: A review of different methodologies,” Renewable and Sustainable Energy Reviews 73 (2017) 854–867.
- S. Mishra et. al, “A comprehensive review on power distribution network reconfiguration,” Energy Syst (2017), 8, 227–284.
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