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An aggregated model for coordinated planning and reconfiguration of electric distribution networks

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A B S T R A C T

This paper proposes a coordinated distribution system reconfiguration and planning model to deal with the problem of active distribution expansion planning. DR (Demand response) programs are modeled as virtual distributed resources to cover the effect of uncertain parameters. A bi-level optimization procedure is developed to solve the proposed model. At the first level, an optimization problem is solved using PSO (particle swarm optimization) algorithm to determine the system expansion and reconfiguration plans. Next, the second level minimization problem is developed based on the sensitivity analysis. The DR programs are taken into account in the second level problem to encounter with the problem uncertainties. Therefore, the proposed model incorporates the problem of DSR (distribution system reconfiguration) with system expansion problem, while the presence of DR is considered to enhance the effectiveness of the problem. The IEEE 33-bus standard test system is utilized to investigate the performance of the proposed model. The simulation results approve the advantages of the proposed model and its economical profits for distribution network owners.

1. Introduction

Distribution system expansion planning problem consists of sizing, timing and siting of distribution facilities, while the restrictions of the system and components are satisfied to provide forecasted load [1,2]. DEP requires a complex optimization procedure due to the nonlinear and combinatorial nature of the problem [3]. Various optimization algorithms are proposed for the best allocation of limited financial resources [4]. Dynamic planning [5], graph-theory models [6], and heuristic algorithms such as simulated annealing, GA, EA, AC, and PSO are the examples of these methods [7–9]. Review of the literature shows that heuristic methods are being used increasingly in spite of their random nature [10,11].

The development of distribution systems, poses new challenges and problems regarding electrification and desired reliability level [12]. Changes in the designing, planning and operation of distribution networks are necessary to cope with the new challenges and requirements of developing systems [12]. A huge burden of research has investigated the planning of distribution networks. The following references are some of the studies in this area of research. Carrano et al. [13] proposed a multiobjective approach to design a distribution system. The objective functions included monetary cost and system failure indices including economical costs of investment, maintenance, energy losses and also failure rate costs. Venkata et al. [12] reiterated the necessity of changes in the designing, planning, operation and management of distribution networks in future power systems. They investigated approaches to cope with such challenges in the developed countries (like the United States and the United Kingdom) and the fastest developing countries (such as China and India). Haffner et al. [2] introduced a multistage model in the planning of distribution networks. The objective function was to minimize the net present value of investment cost, as well as the operation and maintenance costs. The constraints in Ref. [2] consisted of the facilities' operational restrictions, voltage ranges, and logical constraints decreasing the search space. Najafi et al. [14] utilized GA to optimally design a large-scale distribution system. They determined the location and size of substations and medium voltage

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Nomenclatures

Indicators

- y planning years
- n_{cl} network candidate lines
- n_f network feeders
- T time periods
- CT various types of candidate lines
- m bus numbers

Decision variables

- $\chi_{n_{cl}}(y)$ integer variable that is equal to "*CT*" if feeder "n_{cl}" is reinforced with line type "*CT*"; otherwise, it is 0
- $z_{n_{cl}}(y)$ binary variable that is equal to 1 if feeder "n_{cl}" is reinforced in year "y"; otherwise it is 0
- $z_{n_f}(T,y)$ binary variable that is equal to 1 if feeder "n_f" is selected in the time period "T" of year "y"; otherwise it is 0
- $p_m^{DR}(T,y)$ active power enabled with DR programs at bus "m" and the time interval "T" of year "y" [kW]
- $\partial_{n_f}(y)$ integer variable that is equal to "*CT*" if the type of feeder "n_f" is "*CT*"; otherwise it is 0

Variables

- $NPVC$ net present value of total planning costs [$]
- $C^{upg}(y)$ network upgrading cost in year "y" [$]
- $C^{Loss}(y)$ total cost of energy losses in year "y" [$]
- $C^{tr}(y)$ total cost of imported energy from the transmission grid in year "y" [$]
- $C^{DR}(y)$ total DR cost in year "y" [$]
- $C^{R}(y)$ total network reliability cost in year "y" [$]
- $p_{n_f}^{loss}(T,y)$ active power losses of feeder "n_f" in the time period "T" of year "y" [kW]
- $q_{n_f}^{loss}(T,y)$ reactive power losses of feeder "n_f" in the time period "T" of year "y" [kVAR]
- $p^{tr}(T,y)$ imported power from the transmission grid in the time period "T" of year "y" [kW]
- $pf_{n_f}(T,y)$ power flow of feeder "n_f" in the time period "T" of year "y" [kW]
- $C_m^{DR}(T,y)$ cost of DR at bus "m" and the time period "T" of year "y" [$/kW hour]
- $T_m^{DR}(T,y)$ total enabled duration of DR at bus "m" and the time period "T" of year "y" [hour]
- $V_m(T,y)$ voltage level of bus "m" in the time period "T" of year "y" [kV]
- $I_{n_f}(T,y)$ current of feeder "n_f" in the time period "T" of year "y" [A]
- $P_{sub}(T,y)$ amount of injected active power from the distribution substation in the time period "T" of year "y" [kW]
- $Q_{sub}(T,y)$ amount of injected reactive power from the distribution substation in the time period "T" of year "y" [kVAR]
- $q_m^{DR}(T,y)$ reactive power enabled with DR programs at bus "m" and the time interval "T" of year "y" [kVAR]
- $D_m^{DR}(y)$ total enabled duration of DR at bus "m" in year "y"

Parameters

- i discount rate
- $UC(\chi_{n_{cl}}(y))$ installation cost of line "*CT*" per kilometer [$/km]
- $L^{n_{cl}}$ length of line "n_{cl}" [km]
- $C_{n_{cl}}^{f}$ fixed cost of feeder "n_{cl}" [$]
- $t(T,y)$ duration of the time period "T" of year "y" [hour]
- $LC(T,y)$ loss cost in the time period "T" of year "y" [$/kW hour]
- $EC(T,y)$ cost of imported energy from the transmission grid in the time period "T" of year "y" [$/kW hour]
- $\lambda(\partial_{n_f}(y))$ failure rate of line "*CT*" per kilometer and per year [fail/km year]
- $CCLF$ cost of curtailed load per fault [$/kW fail]
- L^{n_f} length of line "n_f" [km]
- $rp(\partial_{n_f}(y))$ average duration of fault on line "*CT*" [hour/fail]
- HEC energy cost per hour of fault [$/kW hour]
- V^{min} minimum permissible voltage level [kV]
- V^{max} maximum permissible voltage level [kV]
- $I_{n_f}^{\max}(y)$ permitted maximum current limit of feeder n_f in year "y" [A]
- $p_m(T,y)$ amount of active load at bus "m" in the time period "T" of year "y" [kW]
- $q_m(T,y)$ amount of reactive load at bus "m" in the time period "T" of year "y" [kVAR]
- $D_m^{DR,max}(y)$ maximum enabled duration limit of DR at bus "m" in year "y"
- $p_m^{DR,max}(T,y)$ maximum penetration level of DR at bus "m" and the time period "T" of year "y" [kW]

Sets

- Λ^{cl} set of all candidate lines
- Λ^{f} set of all network feeders
- Υ set of time periods
- Γ set of all candidate line types
- Ψ set of planning years
- Δ set of system buses

Abbreviations

- *DSR* distribution system reconfiguration
- *DR* demand response
- *DEP* distribution expansion planning
- *GA* genetic algorithm
- *EA* evolutionary algorithm
- *AC* ant colony
- *PSO* particle swarm optimization
- *TBP* time-based program
- *IBP* incentive-based program
- *MBP* market-based program
- *IEA* international energy agency
- *MINLP* mixed-integer non-linear programming
- *NLP* non-linear programming
- *MILP* mixed-integer linear programming
- *AIS* artificial immune systems
- *DSCNO* direct search continuous nonlinear optimization
- *OO* ordinal optimization
- *SFLA* shuffled frog leaping algorithm
- *MPDIPA* modified primal-dual interior point algorithm
- *ABC* artificial bee colony
- *VSLA* variable structure learning automata
- *NDSGA* non-dominated sorting GA