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A new approach for reliability-centered maintenance programs in electric power distribution systems based on a multiobjective genetic algorithm

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ABSTRACT

This paper proposes a multiobjective model to solve the mathematical problem of optimizing reliability-centered maintenance planning of an electric power distribution system (EPDS). The main goal is to minimize the preventive maintenance costs while maximizing the index of reliability of the whole system. In the proposed model, the limits of the indices, such as SAIDI and SAIFI, are considered as constraints of the maintenance programs. The reliability indices of the EPDS components are evaluated and updated by a fuzzy inference system. A NSGA-II algorithm was proposed to solve the multiobjective model that provides an optimized Pareto frontier. The results obtained from applying the proposed methodology to a system with three feeders and 733 components are presented, showing its robustness and quality for maintenance planning in EPDS.

Contents

1. Introduction

Electric power distribution utilities must offer power supply services that have quality, appropriate voltage levels and a low interruption rate. To achieve these goals, specifically quality, regulatory agencies establish power quality indicators for supply services as well as targets and thresholds to be achieved by electric utilities. These companies usually carry out preventive maintenance (PM) programs to improve system reliability by establishing better working conditions to extend the useful life of their equipment [1,2,22].

Distribution system reliability is one of the most important indices for evaluating the service quality of electric power distribution companies [3]. In particular, for a given distribution system and for each year of the regulatory period, regulatory agencies specify

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Nomenclature

Sets

E set of components and devices on the network under study
E_f set of components and devices on the network constrained to feeder $f \in F$
E_{TR} set of distribution transformers
E_{VR} set of voltage regulators
E_{CP} set of capacitor banks
E_{SWP} set of protection and maneuver switches
E_{PC} set of network cables
E_{CB} set of circuit breakers
$E_{VR|ms_i}$ set of voltage regulators constrained to macro-section ms_i
F set of feeders of the EPDS under study
PH monthly period sets of ph, i.e., $PH = \{1, 2, \ldots, ph\}$
PHQ quarterly period sets of ph, i.e., $PHQ = \{1, 2, \ldots, \lceil ph/3 \rceil\}$
PHY yearly period sets of ph, i.e., $PHY = \{1, 2, \ldots, \lceil ph/12 \rceil\}$
M_e set of maintenance tasks defined for equipment $e \in E$
M_{tr} set of maintenance tasks defined for distribution transformers
$M_{sec|e_{tr}}$ set of macro-sections between the distribution transformer e_{tr} and substation distribution
S set of system sections under study
X set of maintenance plans for equipment $e \in E$, i.e., $X = \{x^t_{(e,m)}\}, \quad \forall e \in E, \quad \forall t \in PH$ and $\forall m \in M_e$

Indices

e_{tr} distribution transformers index of E_{TR}
e_{vr} voltage regulator index of E_{VR}
e_{cp} capacitor bank index of E_{CP}
e_{sw} switches index of E_{SWP}
f feeders index of F
m maintenance tasks index of M_e and/or M_{tr}
q time quarterly index of PHQ
s section index of S
t time monthly index of PH
y time annually index of PHY

Constants

$a_1, \ldots, a_5$, and b_1, b_2 coefficients to control the number of maintenances along the planning horizon
$arte_{e_{tr}}$ average response time in an emergency on the equipment $e_{tr} \in E_{TR}$
atd_e average time to dispatch maintenance crews to perform a maintenance task on equipment $e \in E$
$ate_{(e,m)}$ average time to perform/execute the maintenance task $m \in M_e$ on equipment $e \in E$
$atp_{(e,m)}$ average planning time of maintenance crews for performing the maintenance task $m \in M$ on the equipment $e \in E$
$cost_{(e,m)}$ cost of maintenance action m for equipment e
DIC individual interruption duration per customer unit
$dic_{mth}min$ limit value of the monthly indicator DIC for the set of customers supplied by distribution transformer $e_{tr} \in E_{TR}$
$dic_{trim}min$ limit value of quarterly indicator DIC for the set of customers supplied by distribution transformer $e_{tr} \in E_{TR}$
$dic_{year}min$ limit value of yearly indicator DIC for the set of customers supplied by distribution transformer $e_{tr} \in E_{TR}$
FIC interruption frequency individual per customer unit
$fic_{mth}min$ limit value of monthly indicator FIC for the set of customers supplied by distribution transformer $e_{tr} \in E_{TR}$
$fic_{trim}min$ limit value of quarterly indicator FIC for the set of customers supplied by distribution transformer $e_{tr} \in E_{TR}$
$fic_{year}min$ limit value of yearly indicator FIC for the set of customers supplied by distribution transformer $e_{tr} \in E_{TR}$
j monthly update rate of the cost of maintenance task
$\max\{m \in M_e\}$ the highest level of maintenance defined for equipment $e \in E$
ph planning horizon
$t_{feasible_f}$ time of maintenance teams (in hours) to perform scheduled maintenance tasks
$ur_{\max}$ maximum supported value for the failure probability (Unreliability) of capacitor banks
w_s active power loads fed by section $s \in S$

Fuzzy outputs

$C^{ms_i}_{E_{PC}}(t)$ reliability of network cables set of the macro-section ms_i, with $i \in M_{sec|e_{tr}}$ at time t
$C^{ms_i}_{e_{sw}}(t)$ reliability of protection switch $e_{sw} \in E_{SWP}$ of macro-section ms_i, contained in $M_{sec|e_{tr}}$ at time t
$C_e(t)$ reliability of equipment $e \in E$ at time t
$C^{ms_i}_{e_{rt}}(t)$ reliability of voltage regulator $e_{rt} \in E_{RT}$ constrained to macro-section $ms_i \in M_{sec|e_{tr}}$ at time t
$C_{e_{bc}}(t)$ reliability of capacitor banks at time t
$C_{e_{vr}}(t)$ reliability of voltage regulator $e_{vr} \in E_{VR}$ at time t
$C_{e_{tr}}(t)$ reliability of distribution transformer $e_{tr} \in E_{TR}$
$C_s(t)$ reliability of section $s \in S$ at time t

Variables

a^t_e apparent age of equipment $e \in E$ at time t
$P(t)$ failure probability at $t \in PH$
$x^t_{(e,m)}$ binary decision variable to perform (or not) the maintenance task m at time t on the equipment e

the values of these indices based on historical values. In this scenario, the planning operation department (POD) of the utilities can propose different strategies to improve the reliability performance of their distribution systems. Some actions commonly adopted are network maintenance actions to prevent fault events, introduction/reinforcement of control and automation devices, adoption of new network management paradigms (island mode operation in the restorative state), and reallocation or installation of additional switches along the distribution system. However, achieving this goal may involve an increase in planning and operating costs. With the competitiveness of the electricity market, a reduction in the operational and investment costs of the systems is required, which therefore requires reducing the costs of PM programs [27]. These costs constitute the largest expense for companies in this sector [2]. Thus, the optimization of PM programs has become critical for distribution companies to fulfill these two conflicting objectives, i.e., reducing the operational and investment costs and improving the electric power distribution reliability. In this context, reliability centered maintenance (RCM) is presented as an efficient methodology to relate equipment maintenance with system reliability [4,5].