RISK MANAGEMENT APPROACH IN DISTRIBUTION NETWORKS MAINTENANCE SCHEDULE

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ABSTRACT

This paper presents a risk management approach for optimal long-term maintenance schedule of distribution networks. The new model is dealing with selective risk factors. Within that methodology, the new model of state transition based on decision tree diagram is also proposed. New state variables – number of years since the last repair for each preventive maintenance action have been introduced into this model.

The proposed methodology is tested on overhead distribution network, and it has being introduced in EPS Jugoistok Power Distribution Company, for the maintenance schedule and for the prioritizaton o maintenance activites. Obtained results have shown that the expected costs of distribution network maintenance can be reduced and the risk of emerging of significant operation costs minimized, by detailed and realistic modeling of risk factors.

INTRODUCTION

Maintenance schedule of distribution system is timely action plan with purpose to extend life cycle of the system, in order to reduce overall operation costs. Maintenance is closely related to reliability. If maintenance actions are performed rarely, it can cause a large number of faults and outages, while done too often, costs will be greatly increased. Therefore, it is necessary to make an appropriate balance between maintenance costs and outage duration costs.

Risk management based maintenance is the latest approach based on evaluating risk of equipment failure and consequences such failure can produce of functioning of the system [1-3]. The risk approach provides more realistic modeling of equipment failure and estimation of expected consequences. More precisely, quantification of risk enables determining an optimal level of risk that provides the most efficient maintenance strategy for distribution networks.

In the traditional maintenance approaches, usually only one kind of maintenance action has been analyzed - replacement or repair of a particular component, or just one specific activity (inspection or tree trimming). Long term planning is performed either by determining fixed time intervals or from year to year by quasi-dynamic approach .. On the other hand, prioritizing of maintenance activities does not provide a global optimum of costs . Previous work on maintenance strategies in EPS was based on decoupling risk factors and related preventive actions, but in this model simultaneous treatment of more components and risk approach has not been used [4]. In a methodology for determining optimal maintenance strategy, it is therefore necessary to define a model that would unite following demands: 1) decoupling risk factors and related preventive actions 2) determining strategy for long term period, 3) simultaneous treatment of more components. This paper is explaining a methodology solving those problems.

The methodology explained in this paper determines an optimal plan of actions for multi-year maintenance schedule. It is based on the risk approach and the model of decoupled failure risk factors in distribution network. Risk approach enabled more realistic modeling of component failure and estimation of expected consequences, while decoupling risk factors provided an overview of quantitative influence of individual risk factors to reliability and determining the optimal plan of selected actions that have impact to individual risk factors. Within that methodology, the new model of state transition based on decision tree diagram is also proposed. New state variables – number of years since the last repair for each preventive maintenance action have been introduced into this model. Introducing these new variables provides a simple modeling of state transition, as well as efficient application of dynamic programming for solving the model for multi-year period.

RISK MANAGEMENT PROCEDURE FOR MAINTENANCE SCHEDULE

There are seven basic steps of one risk management process, as it has been defined by international standards:

1) Communication and consult
2) Establish the context
3) Identify risk
4) Analyze risk
5) Evaluate risk
6) Treat risk
7) Monitor and review

In this paper emphasis was made only on several among these steps: identification, analysis, evaluation and risk treatment (through a plan of preventive actions).

To determine an optimal multi-year maintenance scenario it is necessary to analyze all possible scenarios and associate to each of them appropriate expected risk. Finally, it is necessary to choose the scenario that minimizes risk of emerging significant operation costs by using appropriate criteria for risk evaluation. For such analysis, the most suitable is the risk management approach that is a process whereby organization methodically addresses the risks attached to maintenance activities with the goal of achieving sustained benefit within each activity and across all activities.

The crucial step is to analyze, e.g. to asses consequences, likelihood and the level of risk. The first task in the process of risk analysis is to determine the model of component failure. In this model, decoupling of risk factors and analysis of risk increase in time was performed. Next, all possible preventive actions that set these decoupled risk factors to initial value were overviewed. Lastly, each of these preventive actions leads the system into a particular state in which evaluating of consequences, or expected costs, is performed. Transition from one state to another is modeled through the state transition model in form of decision tree. This model provides multi-year evaluation of all possible scenarios and estimation of total expected costs associated with each scenario. The dynamic programming technique is used for solving the proposed model, or determining the optimal maintenance scenario. In the end, the model extension for treatment of multiple components was presented.

Risk and Decoupling of risk factors

Risk is defined as multiplication of probability that a failure (fault) can happen, on one side, and expected value of costs that cause this failure in the system, on the other side. The risk is defined on the level of the considered system.

Failure rate (λ) describes probability of failure of the considered component, or the number of times per year that a component can expect to experience a failure. Failure rate is defined on the level of the component. Total failure rate of one component λ_{tot} (t) can be decoupled to several different failure rates:

$$\lambda_{tot}(t) = \sum_{i=1}^{N} \lambda_i \qquad (1)$$

$\lambda_i(t)$ i-th failure rates resulted from corresponding i-th risk factor,

N – number of influencing risk factors.

Each of the different failure rates is associated with one corresponding risk factor that influences reliability of this element. For example, different failure rates of one overhead line can be caused by different risk factor influences (vegetation influence, insulation and supporting equipment failures and faults due to mechanical damage of the poles).

Preventive maintenance actions

Above-mentioned risk factors can be reduced by applying preventive actions. For example: a) minor damages are solved by inspection and minor repairs; b) major damages are solved by larger overhauls; c) vegetation influence is removed by trimming the trees surrounding the power lines. In case in year *t* one of the mentioned actions is performed, the value of appropriate failure rate for this particular factor drops to initial value. In this way, the object after repair is not considered as being “new”, but the risk is reduced only by the one risk factor for which a selective preventive or corrective action has been performed. This decomposition to individual factors provides the influence impact of separate maintenance actions to entire reliability of the distribution network. In general, possible actions that can be taken during maintenance of one object are: 1) not doing any maintenance activity; 2) performing minor repairs and overhaul based on inspection results; 3) performing overhauls in fixed intervals; 4) performing selective actions on a predefined timetable. Some of these actions must be performed on no-load conditions, and some under load. Detailed display of most frequent maintenance actions on an overhead line are given in Table I.

By decoupling individual risk factors it is possible to simultaneously overview several preventive maintenance actions. In fact, each of the influencing factors is associated with one of the actions, which contributes to selective approach that in bottom line reduces total costs.

TABLE I
ACTIVITIES IN OVERHEAD LINE MAINTENANCE

Action	Voltage	Description
Line inspection	On	Visiting line along the corridor in order to check correct condition of insulation, lines, joints, sag control, determining necessary trimming, noticing all adjacent installations , thermo vision recording, grounding measurements.
	Off	Inspection and cleaning of insulators, climbing the poles in purpose of control.
Minor repairs	Off	Straightening poles, replacing insulation, tightening the conductors, replacing voltage arresters, replacing line disconnectors
Tree trimming	Off	Partial or total trimming of feeder corridor

Decision tree for one element

Decision tree for choosing selective actions in maintenance of one overhead line for three-year considered period is presented in Fig.1. Basic tree components are the decision node (depicted as rectangle in Fig.1) and chance node (depicted as a circle in Fig.1). In each node, decisions are defined as different preventive maintenance scenarios (SCRi). These scenarios are obtained by combining separate actions. Each of the scenarios is presented with a branch that starts at the decision node and terminates at the chance node. For each of the scenarios (SCRi) there is an appropriate number of possible outcome or consequences (Oi) that depends on characteristics of the system itself. Finally, Oi(x_1, x_2, x_3) is possible outcome with precisely defined values of variables x_1,,x_2, x_3 in state space. Each of these consequences is presented with a branch that starts at the chance node in Fig. 1. Subsequently, costs are calculated for each of the consequences (C(SCR_i, O_j)). Costs of consequences in each of the scenarios (C(SCR_i,O_j)) are formed by taken preventive actions for this scenario (e.g. costs of inspection and cleaning corridor, cost due to undelivered energy and costs of repair works).

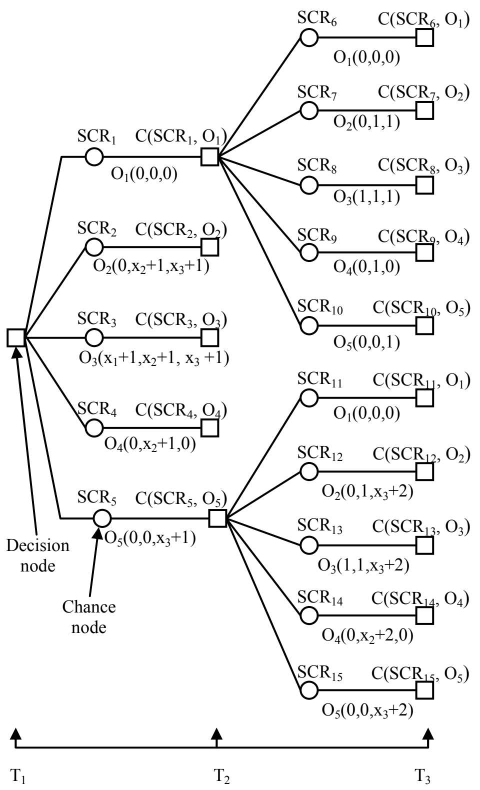

Fig. 1. Decision-tree for three-year maintenance scenario

Each path in presented tree (graph) represents one multi-year scenario of preventive maintenance (SCR_i(t)). The transition scheme for a line is given with three possible actions:

1 – inspection and eliminating minor faults
2- major line overhaul and eliminating major defects.
3 – trimming trees surrounding the line.

The x_i marks time in years since the previous action of type i (i=1,2,3). If a certain action is not performed, the value of appropriate variable x_i is increased by 1 (element is 1 year older), and if action has been performed, the value is set back to 0 (condition of the element is returned to initial for determined set of influences eliminated by corrective action). Also, a scheme of all possible transitions from initial state to all possible states in the next time periods is given. By observing possible transitions from the figure, it is clear that, for example state (0, 0, 0) in second year matches feeder where all three actions were preformed and all possible damaging influences eliminated. State (0, x_2 + 1, x_3 + 1) matches the feeder where inspection and elimination of minor faults has been performed, but the time since the previous major overhaul and trimming trees increases for 1. With the scheme of possible transitions it is possible to consider specifics also of the entire system in terms of various combinations of maintenance actions.

This criterion for risk evaluation corresponds to maintenance scenario in which the total expected costs of maintenance are minimal:

$$d(SCR_{opt}) = \min(\sum_{i=1}^{T} E(SCR_i)\cdot(1+p)^{-i}) \qquad (2)$$

With the following constraints:
$E(SCR_i) \leq E(SCR^*_i)$.
$E(SCR_i)$ - total expected costs in year i
$E(SCR^*_i)$ – maximum allowed costs in year i
p, T - discount rate, planning period

Prioritization of maintenance activities

A long term determination of required level of resources, is not much realistic in the bussines conditions of existing power distribution companies. The more realistic situation is to revise each year the plans that are alredy adopted.
A second phase in implmeting that methodology is to determine, on a yearly basis, a list of maintenance activites, as well the list of prioritized objects for that particular year. The main criterion for the prioritazation of activities is effectivity ratio K= C_0 / C, where C is a minimal value of costs obtained by the use of optimal combination of activities. C_0 is the value of cost with no preventive actions taken.

The algoritm of a methodology is presented on figure 2.

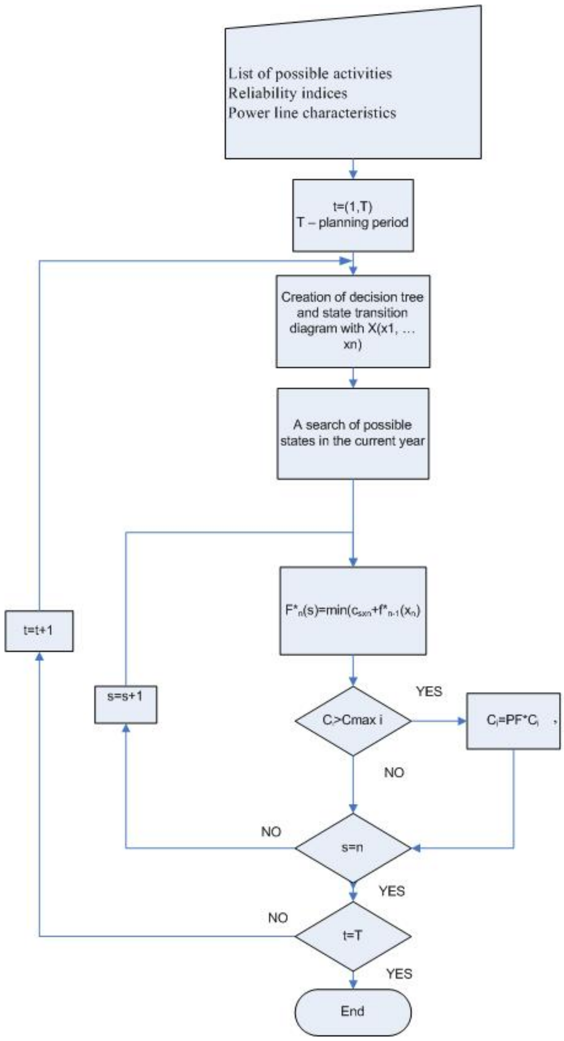

Figure 2. Algoritm of distribution network maintenance schedule

CONCLUSIONS

This paper presents a methodology for determining the optimal multi-year scenario of preventive maintenance that is based on application of risk evaluation and risk management tools and of dynamic programming technique. The essence of the proposed methodology consists of decoupling the risk factors and determining selective action plan, which provides that total risk of expected operation costs in a particular time period is minimal. The resulsts of test examples have shown that application of one such sophisticated method the expected operation costs are significantly reduced in comparison with usual traditional approach of applying overhauls in regular time intervals. In this way, the proposed methodology can become an important analytic tool in conditions of open competition where reducing of operating costs in distribution networks has a great value. The first results of introducing that methodology in EPS Jugoistok power distribution company are very promising.

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