USING FEEDER RECONFIGURATION FOR CONGESTION MANAGEMENT OF SMART DISTRIBUTION NETWORK WITH HIGH DG PENETRATION

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ABSTRACT

One of the main intent of smart grid is to enable more renewable energy resources. Installing the DGs near end-customers result in reduction of power transmission of lines, however, if a large amount of microDGs generate energy simultaneously, it may result in distribution system congestion. In usual, distribution component capacity is considered high enough to avoid any congestion. However, considering the on-line monitoring and controlling abilities of a smart grid, this paper addressed reconfiguration as an effective methodology to solve the distribution network congestion problem. Genetic algorithm is used to determine the optimal configuration. Numerical results of implementing the method on a test system demonstrate that network reconfiguration can be used as an effective methodology to defer the additional investment in distribution systems.

INTRODUCTION

In this section these issues are discussed: an overview on smart grids, distribution feeder reconfiguration, congestion in distribution network, literature review and paper organization.

An Overview on Smart Grids

Smart grid environment facilities the using of distributed energy resources (DER) especially renewable energy resources. The rising share of DGs in distribution system and near the end-customers makes different changes in the system [1]. It is necessary to study the impact of high penetration of DGs in distribution system. The electric customers are not just consumer and they can play as an energy supplier [2]. Moreover load flow in distribution feeders are not just one-directional yet.

A smart distribution system has some other significant features. Sensors, communication and information infrastructure take the distribution system operator (DSO) the ability to monitor and control the system on-line [3]. Unlike traditional network that utilities have to overestimate the amount of network capacity that will be needed, in a smart grid the operator have a more accurate supervision on its network components so it is possible to operate the network more near its capacity. A smart system enables the increasing of network load ability.

Congestion in Distribution Network

Congestion occurs whenever the network is unable to accommodate all the desired transactions due to the violation of one or more constraints [4]. Many studies have been presented a method for solving congestion management in a transmission network [5-6]. As it mentioned in distribution system the network capacity is designed high enough so congestion will rarely occurred. However, if load increasing of a feeder results in the violation of current constraints of a distribution system, the congestion should be solved.

There are some differences between congestion problem in transmission networks and distribution networks. One difference is that transmission systems are operated ring, not rural. The other difference is that – considering deregulation in power system - in transmission network the congestion management is considered as an economical problem than a technical problem. For example in congestion management of a transmission network it is required to consider locational marginal price in problem formulation, but in distribution system the electricity price is equal all over the network. Moreover, It is generally necessary to control actions intended to relieve transmission network overloads do not jeopardize the system N−1 security level. However, in distribution system usually it is not required to take this level of security in account.

Distribution Feeder Reconfiguration

Distribution networks are designed ring to have an acceptable reliability but by putting some switches in normal opened state, there are operated radial. Network reconfiguration is to change the topological structure of distribution feeders by closing some normally opened switches and opening some normally closed switches instead of them. The network configuration should remain radial after the switching operations [7].

In many studies the reconfiguration operation has been used in normal conditions to improve system parameters such as loss, voltage profile and power balancing [8]. Moreover, in some studies reconfiguration is used to restore the interrupted loads in emergency conditions [9]. In this paper feeder reconfiguration is addressed as a solution for distribution network congestion management.

Literature Review

Much have been said and written about the smart grids, reconfiguration and congestion management methods, independently. In [10] a methodology is presented to find the optimal topological configuration of a power transmission system to solve the congestion management. Some other literatures have been proposed which present reconfiguration as a tool suited for congestion management [11-12]. However, as it mentioned there are

many difference in reconfiguration and congestion management problem between distribution and transmission networks.
To the best of our knowledge, no study has been proposed to manage congestion problem of a radial distribution network using feeder reconfiguration.

Paper Organization

The rest of this paper is organized as follows: Section II deals with the problem discussion. Section III present the formulation of the congestion management and reconfiguration operation and explains the proposed solution approach. Section IV provides numerical results and discussions on a test system. Section V provides conclusions.

PROBLEM DISCUSSION

The insertion of numerous distributed generations (DGs) and microgrids in smart distribution systems will bring new challenges and opportunities for operation of the system.
On the one hand, when energy sources are close to the costumers, power transmission decreases and therefore little energy will lose in distribution feeders and more transmission capacity will be opened.
One the other hand, each customer may have several suppliers e.g. wind and PV, CHP and electric vehicles. The generation rates of these suppliers are not determined directly by a central agent like the power utility. The generation rate is based on the customer choice and some other parameters such as solar radiation and wind speed. Therefore, when a large amount of microDGs are on-line in an area with their maximum capacity, they will connect together at a single point and provide power for a larger utility grid. Therefore if the capacity of the network at that point is inadequate, congestions/ bottlenecks will occur. To avoid any congestion occurrence in a smart grid with high DG penetration, additional investment in distribution network is required. However, in most of time the feeder transmission capacity may be adequate and it is not economical to plan a network with overestimate capacity.
In this paper considering communication and information infrastructure of a smart system, feeder reconfiguration is presented as an effective methodology for congestion management of a distribution network with high DG penetration.

THE PROPOSED METHOD

Congestion occurrence in distribution network forces DSO to mitigate customers' energy. So it will use communication infrastructure to send signals in order to make a deviation from the customer's desired amount of energy which they want to buy but they cannot or which they want to sell but they cannot, in turn, it will lead to decrement in customers' satisfaction. In this paper, an affordable network reconfiguration is presented to solve the congestion challenge of a smart distribution grid with considerable numbers of microDG. The proposed methodology aims to determine a network configuration in which the value of electricity energy which customers would like to offer it to the utility but they cannot because of the occurring congestion is the minimum.
Through cooperation and competition among the population, population-based optimization approaches, such as genetic algorithm (GA) and PSO, often can find good solutions [8]. Therefore, a genetic algorithm (GA) search is adopted to solve the reconfiguration problem. The main objective is to minimize the branch overloads. However, if there is not congestion in network, it is assumed that a configuration with the minimum loss is the optimum configuration.
In most of reconfiguration problems the constraints are the voltage magnitude at each bus, current magnitude at each branch and also meeting the radial configuration of network constraint. Lines current and buses voltage constraints are expressed as follows:

$$V_{\min} \le V_i \le V_{\max} \qquad (1)$$

$$|I_i| \le I_{\max} \qquad (2)$$

Where $V_{\min}$ and $V_{\max}$ are the minimum and maximum allowable voltage magnitudes and $I_{\max}$ is the maximum current magnitude, respectively. However, in our problem as congestion has been occurred, these network constraints are not met.
A penalty function is defined for each of these constraints to restrict them in the allowable level in obtained results. Therefore, the fitness function for a configuration can be calculated as follow:

$$FitFun = F_{penaly,V} \times F_{penaly,I} \times f(x) \qquad (3)$$

Where $F_{penalty,V}$ and $F_{penalty,I}$ represent total penalty function for voltage and current constraints violation, respectively. Moreover, $f(x)$ represents the network loss. These parameters are calculated as below [13].

$$f(x) = \sum_{l=1}^{Nl} R_l * I_l^2 \qquad (4)$$

$$F_{penalty,V} = \prod_{i=1}^{Nb} f^{i}_{penalty,v} \qquad (5)$$

$$F_{penalty,I} = \prod_{i=1}^{Nl} f^{i}_{penalty,i} \qquad (6)$$

Where Nb and Nl are the number of buses and lines,

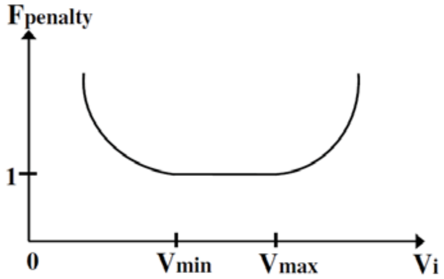

Fig. 1: Voltage penalty functions used to compute fitness function [13]

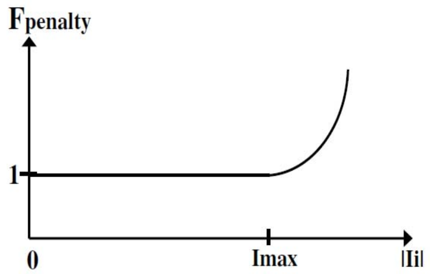

Fig. 2: Current penalty functions used to compute fitness function [13]

respectively. Moreover, R_l and I_l are line resistance and line current, respectively.

$f^{i}_{penalty,v}$, voltage penalty function for bus i, is drawn in Fig.1. Moreover, a similar function is also used for current of all lines, as shown in Fig. 2.

After determining the optimum configuration, it should be checked if it violates the constraints or not. If the optimal configuration does not meet all the constraints yet, it is required to determine the energy amount of each customer in a way that no constraint becomes violated.

To do this, it is considered that the optimal determined configuration is fixed and the objective function is to minimize the violation from customer desired energy. If the network is large GA is used to solve the problem.

NUMERICAL STUDY

The effectiveness of the proposed algorithm is verified using several test systems. The numerical results of a 33-bus test system [14] are presented here (Fig.3). Using GA the optimum configuration is determined. As it can be seen from Table I, in the optimal configuration switches number 7. 11, 32, 34 and 37 are opened and the system loss is 142.6 kW. It is assumed that the capacity of each line is 2 times of the line loading of this optimum configuration.

Fig.4 shows a DG is installed in bus 8. If the DG generates 500 kW and 250 kvar, system loss will be 121.885 kW, but congestion will occurred in line 8. To manage this congestion GA algorithm is used and the optimal configuration is determined. Switch number 34 should be closed and switch number 14 should be opened instead. As it can be seen from the table reconfiguration can solve the congestion management so it is not needed to mitigate customer loads or DG generation.

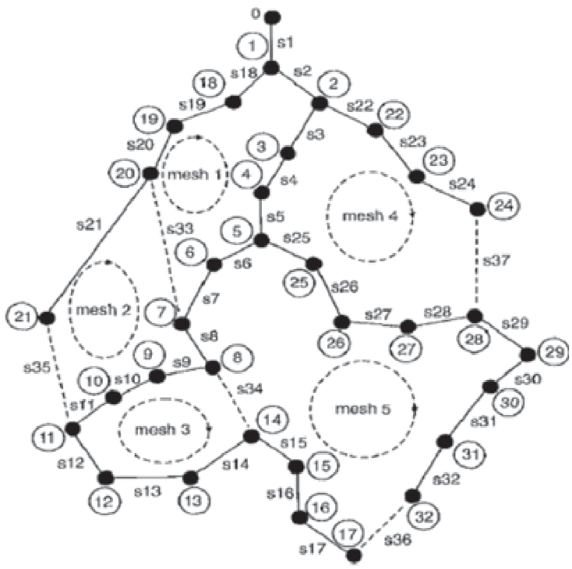

Fig. 3: Original 33-bus distribution network with assigned nodes and switches

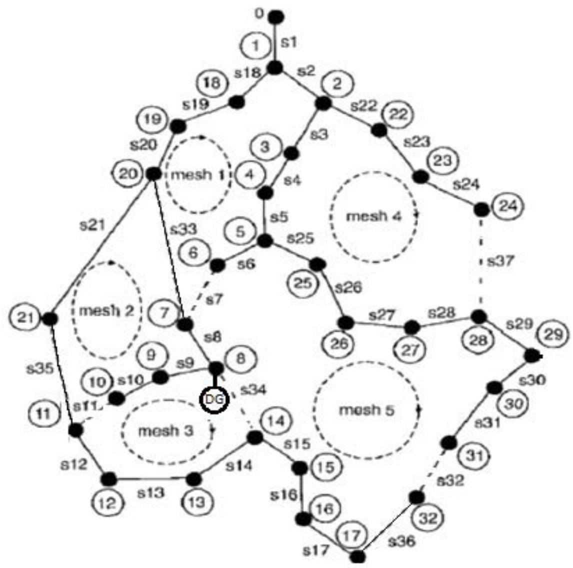

Fig. 4: Installing a DG on bus 8 of the system

Table I
Numerical results of 33 bus test system

	Normally Opened Switches	Loss (kw)	Congestion Occurrence
Base Configuration	33-34-35-36-37	202.6	Not studied
Optimum Configuration	7-11-32-34-37	142.6	No
System with DG before Reconfiguration	7-11-32-34-37	121.9	Yes
System with DG after Reconfiguration	7-11-14-34-37	112	No

CONCLUSION

The widespread use of microDGs near the end-customers is a feature of smart grids. It is not economical to take all the possible consuming and supplying states of customers in network into account and plan an overestimated network to answer all these states. That is because in most of times the network loading will be much lower than the planned network. However, considering sensors, information and communication infrastructures of a smart system, DSO can supervise the network and if any congestion would be occurred, control the network to avoid congestion. In this paper feeder reconfiguration was addressed as an effective methodology for distribution networks congestion management. Simulation results show the effectiveness of the proposed method.

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