RECONFIGURING DISTRIBUTION GRIDS FOR MORE INTEGRATION OF DISTRIBUTED GENERATION

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ABSTRACT

Increasing penetration of distributed generation (DG) is one of the characteristics of smart grids. The conventional distribution grid was not designed for the integration of DGs. Hence the integration of DGs into the distribution grid presents a few challenges to the operation of distribution network. This paper addresses some of these challenges and uses the concept of reconfiguration as a solution to meet these challenges. By reconfiguration, the maximum voltage at each node of the test network was kept within limits, thus mitigating the over voltage problem due to increased DG penetration. Since the reduction in number of switchings due to reconfiguration will help reduce the operation cost, this paper incorporates the objective of minimizing switching as well. The number of switchings could be reduced from six to two for the test network under consideration. Also it has been shown in this paper that reconfiguration can help in deferring the investment required in a transformer like adding on load tap changer.

INTRODUCTION

In this era of smart grids, any concept that helps in improving the efficiency, reliability, cost effectiveness etc. of the power grid is very relevant. Grid reconfiguration is one such concept. It is defined as altering the topological structure of distribution feeders by changing the open/closed states of sectionalizers and tie switches so that the objective function is minimized and the constraints are met [1]. From the above definition of distribution grid reconfiguration it can be understood that it involves optimization. Involving optimization means that there has to be one or more objectives. This paper considers the objective of minimizing over voltage due to increased distributed generation (DG) penetration. Since reconfiguration is an optimization problem it calls for the use of an optimization technique. This paper uses Genetic Algorithm (GA) for this purpose.

GA is a metaheuristic optimization method, that is, it iteratively solves a problem by improving the candidate solution based on certain criteria. It is based on the principle of evolution. GA, being a stochastic optimization method has probabilistic elements incorporated into the algorithm which helps it in escaping from the local optimum and find the global optimum. The major steps involved in a typical GA are initializing the population, crossover, mutation, selection and termination based on the termination criterion. By using crossover operation, two parents are combined to form offspring. Mutation operation adds randomness to the population and hence will prevent the search from being caught in local optima [2].

The following section discusses existing work in the field of grid reconfiguration followed by a section on problem statement. Results and conclusions are discussed thereafter.

LITERATURE REVIEW

There can be various objectives for reconfiguring a grid. Reference [3], [4], [5] performs distribution grid reconfiguration with an objective of reducing losses. Reference [6] aims at configuring a distribution grid for minimum loss considering N-1 security of DG. Distribution network reconfiguration with reliability constraints are discussed in [7]. Multiple objectives for grid reconfiguration during faults are discussed in [8]. Distribution network reconfiguration with an aim of phase load balancing is described in [9]. Reference [10] includes network reconfiguration and loss allocation for distribution systems with DG. Network reconfiguration for minimum power loss in balanced and unbalanced distribution systems with high penetration of DG is presented in [11]. Reference [12] discusses reconfiguration considering variable demand.

Grid reconfiguration presents challenging issues due to the non-convex optimization needed because of non-convex objectives and integer constraints [4]. It belongs to the category of nondeterministic combinatorial optimization problems (NP-hard) [5], [6]. Metaheuristics methods like GA, Particle Swarm Optimization, Simulated Annealing or their variations are commonly used in solving such problems [1], [4], [7], [13], [14]. Reference [15] gives an overview of the relevance of grid reconfiguration in smart grids and the use of GA as an optimization tool in achieving the control objectives. Reference [16] shows that for a small test network and for single objective as being dealt within this paper, GA is a good choice.

This paper uses the concept of grid reconfiguration to addresses the problem of over voltage and grid investment as DG penetration increases. The novelty of the paper is that it uses a real world network as a test network and the load and photovoltaic (PV) profiles used in this paper are realistic. This work focuses on reconfiguration in the context of increasing PV in LV grid in the region of Flanders in Belgium under the project LINEAR [17] and NGINFRA [18].

PROBLEM STATEMENT

As DG penetration in a distribution network increases there occurs over voltage in the system. This affects the power quality. In order to maintain the quality of power, there arises a need to curtail DGs or put a limit on the allowable penetration of DGs in the network. Since most of the DGs use renewable sources of energy, it is better to include as much of DGs as possible because of its environment friendliness. Also, when PV penetration increases, the difference between maximum and minimum voltage level within which the transformer has to operate decreases compared to a situation without DG. Sometimes it even happens that the minimum voltage limit is greater than the maximum voltage limit. In order to meet this requirement on-load tap changer (OLTC) is required which adds to the investment cost. This paper addresses these problems and shows that grid reconfiguration is one of the ways to mitigate them. This is shown with the help of a test network as described below.

Test network

Fig.1 shows the initial configuration of the test network. It is a 400V distribution network. It represents a residential semi-urban distribution grid in Flanders. There are 70 nodes in the network out of which 62 nodes have houses connected to them. Each of the houses is assigned a load profile with a time step of 15 minutes for a whole year. It is assumed that switches are available on all the lines connecting any two nodes. Thus for the 70 nodes test network, there are 69 switches present, plus there are three additional switches which when closed can connect node 16&28, 34&38, 51&70 respectively. These switches are available inside the three reconfiguration boxes installed by the Distribution System Operator.

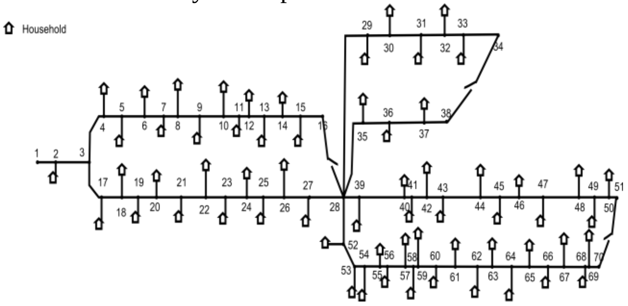

Figure 1: 70 node, LV test network

Assumptions

1. The test network is a balanced three phase network
2. All loads are residential loads and are assigned a load profile typical of Flanders
3. All loads are single phase
4. There is a possibility of connecting single phase PVs to each load
5. The PV profile (with a time step of 15 minutes for a whole year) for all PVs is the same since they are geographically closely located
6. There are switches available in the LV distribution network that can be opened and closed. Depending on the status of the switches, the topology of the grid changes. Present day LV networks do not have any of these switches except at the end of some of the feeders. This assumption is made from a futuristic point of view wherein the availability of these switches should be considered as an investment towards smart grids. Also, the simulation results show that the switches are not needed between all the nodes but between selected nodes.

Fig.2 depicts the box plot of nodal voltages for phase 3. It shows the minimum and maximum values for the voltage at each node over a period of one year. Standards for voltage level in distribution system can be found in [19]. In the normal configuration (as shown in Fig.1) of the distribution network, with a 40% penetration (i.e. the percentage of houses with PVs connected to them) of 5kW PVs and 100% load penetration there is over voltage (voltage >253V (110% of 230V), that is, voltage > 1.1 p.u) in some of the nodes in the network as shown in Fig.2.

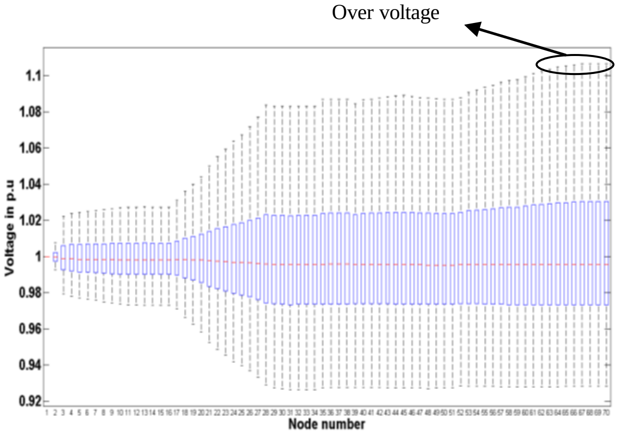

Figure 2: Box plot of nodal voltage (phase 3) at each node for the initial configuration

This over voltage can be avoided by reconfiguring the network with the help of opening and closing the switches. The addition of switches and their opening & closing involves a cost which has to be minimized.

For a given PV profile, load profiles, PV penetration level & load levels, to limit the highest voltage at any node to 253V, the transformer secondary voltage should not be more than a certain maximum value. Also, under the same conditions, in order to keep the 95th voltage percentile at or above 207V (90% of 230V) and the lowest voltage at any node greater than 195.5V (85% of 230V), the transformer secondary voltage should not go below a certain minimum value. Since the highest nodal voltage and the lowest nodal voltage occur at two different points of time, the transformer tap can be changed accordingly in order to overcome the problem. But then it calls for the installation of taps in transformer. Thus the problem is to defer such active measures in transformer.

Objectives

1. To maximize DG penetration
2. To maximize DG penetration & minimize switching
3. To defer active measures in a transformer

Constraints

1. The reconfigured network should always be radial (radialty constraint)
2. All the loads should be supplied with electricity (load-serving constraint)
3. The nodal voltages should be within limits

RESULTS & DISCUSSION

GA was used to find the configuration that resulted in zero (no) nodes with over voltage. It is found that there is more than one configuration that will achieve the desired objective. Fig.3 is one such configuration. The circles are used to highlight the changed switch positions. Fig.4 shows the plot of node voltage vs. node number for the configuration. It can be seen that there are no nodes with voltage greater than 253V.

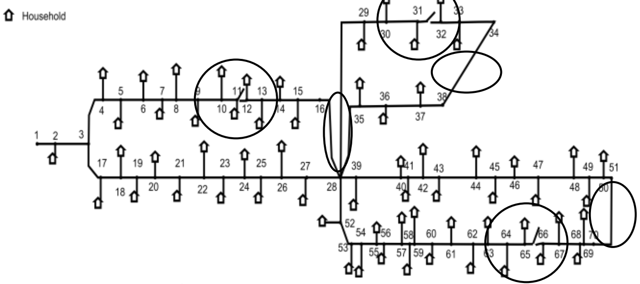

Figure 3: Reconfigured grid with no over voltage

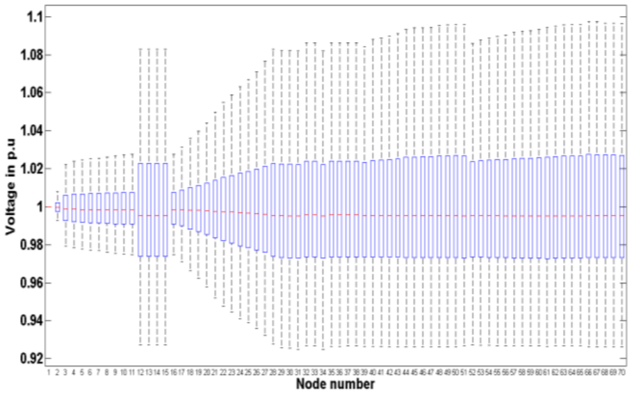

Figure 4: Plot of node voltage vs. node number for configuration with no over voltage

An additional objective of minimizing the switching that will result in minimizing the investment and operation & maintenance cost of switches was included in the algorithm. Thus a multi-objective optimization was performed. The number of configurations that achieved both objectives was a subset of the solutions (configurations) that were obtained in the previous simulation. Fig.5 shows the reconfigured network in which the number of switchings is less (two, one opening and one closing) compared to the configuration in fig.3 where the number of switchings is six. Fig.6 shows the resulting nodal voltages.

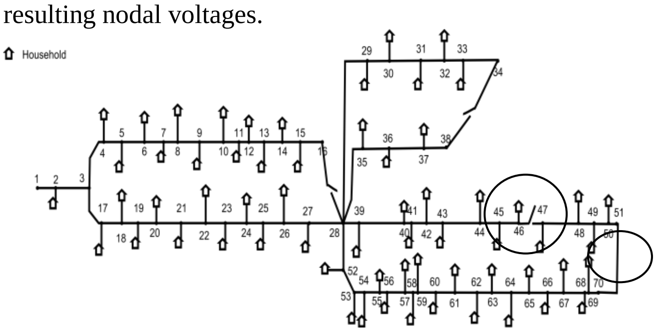

Figure 5: Reconfigured grid with no over voltage & minimum switching

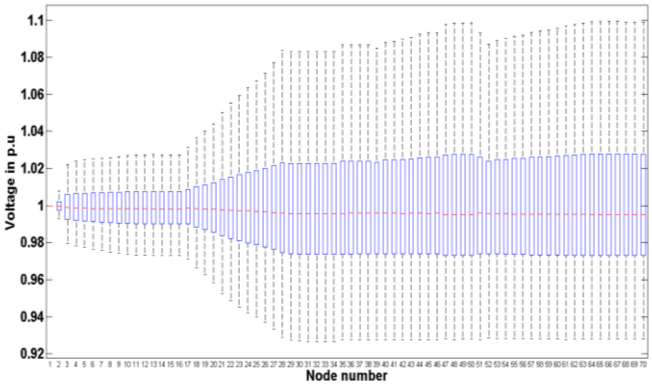

Figure 6: Plot of node voltage vs. node number for configuration with no over voltage & minimum switching

For the initial configuration as shown in fig.1, with a load penetration of 150% and PV penetration of 38%, the difference between the maximum and the minimum value of the transformer secondary voltage is negative (-0.4593 V), which is not achievable unless active measures like adding on-load tap changers are taken. Fig.7 shows the result of reconfiguration for deferring such active measures in a transformer, for which the difference between maximum and minimum value of the transformer secondary voltage is positive (1.3759V), which is achievable.

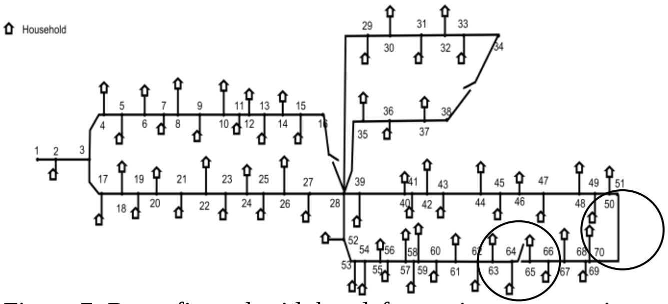

Figure 7: Reconfigured grid that defers active measures in the transformer

Intuitively, over voltage normally occurs at the end of the feeders. Hence the availability of switches towards the end of the feeders is crucial. If the availability of the switches is less, then the DG penetration level that the network can withstand will also be less. If the load and PV profile is highly varying, that is, huge changes occur within short intervals of time then the position of switches to be opened and closed will also drastically vary. This results in frequent operation of the switches which in turn will result in increased O& M cost of the switches. Also, if the O&M cost of the switches is more than the benefit of having an increased amount of DG in the network, then reconfiguration is not a viable solution unless there are strong regulatory measures in place. These measures should ensure economic profitability since reconfiguration contributes to increased penetration of renewable resources as shown in this paper which in turn will lead to sustainable development. In short, the investment cost, the O& M cost and the availability of switches are the limiting factors in reconfiguring a grid.

CONCLUSION

Reconfiguration helps in mitigating over voltage problem arising due to increased DG penetration. For the test network considered in this paper, with the help of reconfiguration, the maximum voltage at each node of the test network was kept within the limit of 253V. Also, an added objective of minimizing the number of switching when reconfiguring a network helps in reducing the operation cost when simultaneously meeting the power quality requirements. For the test network, the number of switchings could be reduced from six to two. Also, it can be concluded from the results of this paper that reconfiguration can help in deferring the investment required in a transformer like adding on load tap changer.

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[17] LINEAR is the short form for Local Intelligent Networks and Energy Active Regions. More information can be found at http://www.linear-smartgrid.be/[as of 06-Feb-2013]

[18] NGINFRA is the short form for Next Generation Infrastructures. More information can be found at http://www.nextgenerationinfrastructures.eu/ [as of 06-Feb-2013]