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Effect of network reconfiguration on power quality of distribution system

Yadaiah Ch *, S.K. Goswami [1], Debashis Chatterjee [2]

Department of Electrical Engineering, Jadavpur University, Kolkata 700032, India

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ABSTRACT

Effect of network reconfiguration on power quality issues of distribution system has been investigated. The problem of network reconfiguration is reformulated with an objective to improve the power quality of the distribution system. Along with the traditional objective of loss minimization, power quality related objectives such as minimization of harmonic distortion of the voltage waveform, minimization of voltage unbalances at the nodes and maximization of sag voltages are identified as the objectives of reconfiguration. Branch exchange technique has been used to establish each of the objectives. The problem has also been formulated as a multi-objective optimization problem. The multiple objectives are, however, incorporated into a single objective using weighting multipliers and branch exchange technique has been judicially applied to take care of all the objectives. It is found that network reconfiguration can be used as an effective tool to improve the power quality of distribution system. Besides, the distributed energy sources also have great impacts on distribution network, as their size and locations are found to have great importance on the power loss, voltage sag, voltage harmonic distortion and unbalance. The effectiveness of the network reconfiguration on power quality issues have been studied on 25-bus network and IEEE 33-bus network with and without presence of distributed generation and VAr sources.

Introduction

Reconfiguration of distribution network has long been identified as a very useful method for the improved performance of the system. Merlin and Back [1] were the first to propose the network reconfiguration technique for loss minimization of the system. Later on many researches have been reported in the literature with the objective of loss minimization [2–9], load balancing [10–12], service restoration [8,12], voltage profile improvement [9,13,14,33]. Initial attempts were restricted to the balanced radial networks [2,7]. More recently, attempts have been reported to apply the technique on unbalanced networks as well [15–17].

Placement of shunt capacitors is an established technique for voltage and reactive power control in distribution system and researches on the placement and sizing of shunt capacitors have been reported extensively in the recent past [15–21], other form of 'VAr' compensators, like STATCOM are also being used [22].

Installation of small capacity Generating sources, popularly known as the Distributed Generation (DG) sources, in the low voltage distribution network is being encouraged during the recent years for several reasons [24–27]. Network reconfiguration problem has been solved in association with the solution of the capacitor placement problem [15,21,22].

Reconfiguration technique has also been applied on distribution system having DG penetration [24,27]. Some of the publications have formulated and solved the complexity of the DG and capacitor placement problem along with network reconfiguration [9].

In recent years power quality issues have received considerable attention from the researchers and system engineers. Of the various power quality problems, voltage sag and harmonics issues are treated with intense attention because of the increased use of sensitive loads [18,30] in the distribution system.

In this context the impact of network reconfiguration on voltage sag, harmonics and unbalance in distribution system has been investigated in this paper. Several researches have also been reported to have considered the network reconfiguration problem along with the power quality improvement problem. In [23,34] reconfiguration problem has been solved to minimize power loss and voltage sag problem. In [14], loss minimization, reliability and voltage sag enhancement are incorporated in the reconfiguration

* Corresponding author. Tel.: +91 8296925123; fax: +91 3324132384.
E-mail addresses: yadaiahch@gmail.com (Y. Ch), skgoswami_ju@gmail.com (S.K. Goswami), dcchatterjee@ee.jdvu.ac.in (D. Chatterjee).
[1] Tel.: +91 9433960982.
[2] Tel.: +91 9433887966.

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problem. In [22], and all the power quality issues are included in the formulation of the network reconfiguration problem along with the minimization of power loss. In the present paper a new formulation of the problem has been presented. Branch exchange technique [2,29] has been applied to determine the optimum reconfiguration strategy so as to minimize the effects of various power quality issues along with the networks losses. Simulation results performed on a 25-bus network has been presented to justify the proposed concept.

The problem of network reconfiguration

Distribution network is radially configured for operational advantages [2,7,19,31,33]. However, in medium voltage networks tie/sectionalizing switches are provided such that network configuration may be altered to satisfy some operational requirements. The change of the configuration alters the power flow path in the network resulting in altered line currents, node voltages, and degree of unbalances and also level of distortion of the node voltages in presence of harmonics. Since the impedance of the power flow path also changes due to reconfiguration, the voltage available at a node during a voltage sag condition is also liable to be changed. As voltage sag may involve tripping of the sensitive loads, it is apparent that having an improved sag voltage has the potential to reduce the loss of the system under a voltage sag condition. Moreover, change in the effective impedance of the power flow path and the mutually induced voltage due to changes in the line current distribution will result in the change of the harmonic content of the node voltages. Thus, a better and more desirable reconfiguration scheme would take care of all these issues to maximize the benefit of network reconfiguration in distribution system.

Thus, the objectives of network reconfiguration may be formulated as:

Minimize Power loss in the network.
Maximize Sag voltage in the network during fault or switching.
Minimize Harmonic distortion of the node voltages.
Minimize System unbalances.

The above stated objectives may be expressed as:

(i) *Minimization of power loss*

$$Minimize,\ P_{loss} = Re\left(\sum_{m=1}^{l}\left(\sum_{j=a}^{c}(V_j(p)-V_j(k))I^*(m)\right)\right) \quad (1)$$

where
l = number of lines,
$V_j(p)$ = voltage at pth node of jth phase,
$V_j(k)$ = voltage at kth node of jth phase,
$I^*(m)$ = current conjugate of mth line between pth node and kth node,
$j = a, b, c$ phases.

(ii) *Maximization of Voltage sag*: Sag voltage is measured as the remaining voltage of a bus during a voltage sag condition. For the present work, we have attempted to maximize the average sag voltage of the network which is represented as

$$V_{sag,av} = \frac{1}{m}\sum_{j=1}^{m}\left(\frac{1}{n}\sum_{i=1}^{n}V_i^j\right) \quad (2)$$

V_i^j = voltage magnitude in p.u. at ith node for a fault at node j, $i = 1, 2, 3, \ldots, n$, n = number of busses,
$j = 1, 2, 3, \ldots, m$, m = number of fault events considered, and
$V_{sag,av}$ = average node voltage under voltage sag condition.

(iii) *Minimization of Harmonic distortion:* It is measured in terms of the total harmonic distortion of the node voltage (V_{THD}) measured as

$$\%V_{THD,i} = \frac{V_{di}}{V_{rms,i}} \times 100 \quad (3)$$

where

$V_{rms,i} = \sqrt{(V_{1,i}^2 + V_{d,i}^2)}$
$V_{d,i}$ = distortion component of the node voltage
$V_{d,i} = \sqrt{\sum_{h=2}^{m} V_{h,i}^2}$

For the minimization of the voltage harmonic distortion, the maximum value among all the node voltage THD's are minimized. Mathematically, the problem is written as:

$$Minimize\ Max(V_{THD,i}), \quad i = 1,2,3,\ldots,n \quad (4)$$

(iv) *Minimization of System unbalance:* It is basically due to unbalanced loading of the system. In this paper system unbalance is measured in terms of the average value of the node voltage unbalances $V_{unb,av}$ [37] and the problem is represented as

$$Minimize,\ V_{unb,av} = \frac{1}{n}\sum_{i}^{n}\left(\sum_{j=a}^{c}\left(100\frac{|V_{Neg,i}|}{|V_{Pos,i}|}\right)\right) \quad (5)$$

where

$V_{Pos,i} = \frac{1}{3}(V_i^a + \alpha_1 V_i^b + \alpha_2 V_i^c)$
$V_{Neg,i} = \frac{1}{3}(V_i^a + \alpha_2 V_i^b + \alpha_1 V_i^c)$
$\alpha_1 = complex(-0.5, 0.866)$,
$\alpha_2 = complex(-0.5, -0.866)$,
$V_{Pos,i}$ = positive sequence voltage at ith node,
$V_{Neg,i}$ = the negative sequence voltage at ith node,
V_i^j = voltage at ith node of jth phase.

The above mentioned objectives are to be established subject to the satisfaction of the following constraints:

Equality constraint: Power balance at the nodes

$$P_i + jQ_i = V_{ai}I_{ai}^* + V_{bi}I_{bi}^* + V_{ci}I_{ci}^*, \quad i = 1,2,3,\ldots,n \quad (6)$$

Inequality constraints are:

Node voltage limits: $V^{min} \leqslant V_{pi} \leqslant V^{max}$, $p = a, b, c$, $i = 1, 2, 3, \ldots, n$.
Line 'p' capacity limits: $I_{pl} \leqslant I_{pl}^{max}$, $p = a, b, c$, $l = 1, 2, 3, \ldots, L$.

Node voltage unbalance limit:

$$\frac{|V_{Neg,i}|}{|V_{Pos,i}|} \leqslant V_{unb}^{max}, \quad i = 1,2,3\ldots,n.$$

Voltage distortion limit : $V_{THD,i} \leqslant V_{THD}^{max}$

Limit on voltage sag : $V_{sag,av} \geqslant V_{sag}^{min}$

where V_{sag}^{min} is the specified minimum voltage under voltage sag condition.

In addition to the above, network configuration in distribution system is restricted to be radial.

This may be represented as:

$$n_b = n - 1 \quad (7)$$

where n_b = number of active branches i.e., Total number of branches–total number of tie branches. Also, no node would remain islanded. This is represented as: