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Power system reconfiguration in a radial distribution network for reducing losses and to improve voltage profile using modified plant growth simulation algorithm with Distributed Generation (DG)

R. Rajaram, K. Sathish Kumar *, N. Rajasekar

School of Electrical Engineering, VIT University, Vellore 632 014, Tamilnadu, India

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ABSTRACT

Network reconfiguration which is constrained non linear optimization problem has been solved for loss minimization, load balancing, etc. for last two decades using various heuristic search evolutionary algorithms like binary particle swarm optimization, neuro-fuzzy techniques, etc. The contribution of this paper lies in considering distributed generation which are smaller power sources like solar photovoltaic cells or wind turbines connected in the customer roof top. This new connection in the radial network has made unidirectional current flow to become bidirectional there by increasing the efficiency but sometimes reducing stability of the system. Modified plant growth simulation algorithm has been applied here successfully to minimize real power loss because it does not require barrier factors or cross over rates because the objectives and constraints are dealt separately. The main advantage of this algorithm is continuous guiding search along with changing objective function because power from distributed generation is continuously varying so this can be applied for real time applications with required modifications. This algorithm here is tested for a standard 33 bus radial distribution system for loss minimization and test results here shows that this algorithm is efficient and suitable for real time applications.

1. Introduction

The per capita Electrical energy consumption of any country is an indication of its growth and the quality of life of the people, it is used widely in buildings for Heating, Ventilation and Air conditioning (HVAC) in countries like USA (for heating) and in Gulf countries (for cooling). The electrical energy is also used in industries for manufacturing and in traction for transporting. Major source for power generation is still coal which is burned to produce power and carbon dioxide which is the main reason for global warming because it obstructs the reflection of sunlight back from Earth. The Thermal power plants are located either near coalmines or near ports and energy travels long distance to consumers with higher voltages in steps to reduce losses. Radial type of distribution is used because it is easy to operate and set protection devices in a unidirectional power flow. A distribution generation (DG) uses distributed generation units (DGU) which generates electrical power from a nearby energy sources on the type of availability like the solar cells or concentrators, wind turbine, etc. which reduces strain on the main transmission line, increases reliability, reduces cost of power generation and saves non-renewable power resources. There is always an uncertainty of loads on different feeders with respect to time so reconfiguration a method to open few sectionalizing switches and closing few tie switches called distribution network reconfiguration (DNR) has been dealt for last two decades with an objective to reduce power loss, to balance loads and to improve voltage profile, etc. by using different algorithms which can give faster convergence for deciding the switches in DNR, to decide the value of power that can be drawn from DGU in DG.

The network reconfiguration which itself is a complex combinatorial problem has been further complexed by addition of DG as it has many advantages. Merlin and Back (1975) first proposed this reconfiguration using branch technique the problem was 'n' line section switches will have 2^n possible system configurations which will consume more calculation time. Shirmohammadi and Hong (1989) suggested a heuristic algorithm based on Merlin and Back (1975) but without simultaneous switching of feeder reconfiguration. Civalnar et al. (1988) suggested a heuristic algorithm where a simple formula for branch exchanged power loss calculation was developed considering only one pair of switching operation at a

* Corresponding author. Tel.: +91 9443623508; fax: +91 416 2243092.
E-mail addresses: rajaram_rpg@rediffmail.com (R. Rajaram), kansathh21@yahoo.co.in (K. Sathish Kumar), natarajanrajasekar@gmail.com (N. Rajasekar).

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time. Das (2006) used an algorithm based on fuzzy logic. The genetic algorithm was used by Nara et al. (1992) later Zhu refined the genetic algorithm by introducing competition in cross over and mutations (Zhu, 2002). Sathishkumar and Jayabarathi (2012) used chemo taxis on bacterial growth in bacterial foraging optimization algorithm, Imran and Kowsalya (2014) found good fire works in fireworks algorithm, all the above methods used only reconfiguration which is opening or closing the sectionalizing or tie switches in a distribution system without considering DG.

Radial distribution system is generally used as it is easy to design, operate and to place the protective devices. The power flow is unidirectional from generating station to the consumer by stepping up and down the voltages so as to have a minimum power loss in transmission system. The power flow was unidirectional upto the introduction of the distributed generating units (DGU), these units use locally available energy sources to generate power but the power flow has become bidirectional sometimes causing instability in the operation of the system. The renewable energy sources with thyristor controls are widely used to harvest optimal power, innovative use of idle solar power controllers in night for reactive power control are carried out for optimal usage (Varma et al., 2011). The DGU may be sometimes a parked hybrid or electric vehicle connected to grid for supplying power during peak consumption periods and charging the batteries during non-peak periods thereby earning some money for consumer due to difference in energy cost during peak and other periods as demonstrated by university of Delaware in United states of America (USA) in their vehicle to grid project.

The placing and sizing of DG in distribution systems has been studied using Lagrangian based method by Rosehart and Nowicki (2002) later Celli et al. (2005) using genetic algorithm. Wang and Nehir (2004) used analytical methods. Agalgaonkar et al. (2004) used standard market design (SMD) frame work. All the above methods explain about the effects of placing DG in a distribution system without reconfiguration.

The simultaneous reconfiguration and placing DG with proper sizing has been shown by Rao et al. (2013) using harmony search algorithm (HSA) which worked on creating harmony in music principles. Artificial bee colony algorithm based on onlooker and scout bee's was used by Murthy et al. (2012). Nayak (2014) used hyper cube ant colony algorithm based on pheromone scent tracking by ants inside hypercube frame work. All the above methods explain about simultaneous DG placement with reconfiguration advantages over only reconfiguration and only DG options for radial distribution system. Now a days where power networks are deregulated so reconfiguration with DG is meaningful and realistic for real time applications in power industry.

The load as well as the generation varies with time continuously so an evolutionary algorithm which can deal with variations in load and generation is the Plant Growth Simulation Algorithm (PGSA) which is based on the plant growth process the root is the initial point of growth which is similar to initialization, then growth of the trunk and branches occur from nodes which is like searching for optimal values. Modification in evolutionary algorithms is done to make the convergence faster for making them suitable for real time applications. In this paper modification on the PGSA has been carried out and simulations are carried out to demonstrate the advantage of faster convergence of the proposed algorithm (MPGSA) over other algorithms for applications in DNR with and without DG.

The main advantage of MPGSA is that constraints and objective function are dealt separately.

2. Distributed generation (DG)

There are various types of DGU like solar Photovoltaic panels which can supply only real power at unity power factor. Some DGU can supply real as well as reactive power like solar thermal turbo-alternators, biomass or biogas turbo-alternators, wind turbines. In this paper we have considered only 3 numbers of DGU with capacity of 2 M.W working at unity power factor.

There are many benefits of distributed generation like loss reduction, greener environment, improved utility of system, reliability, voltage support, improved power quality, transmission and distribution capacity release and many more (Wu et al., 2010).

3. Problem identification

3.1. Objective function of the problem

The objective function of the problem is formulated so as to get maximum power loss reduction in distributed system which is the sum of power loss reduction due to reconfiguration as well as connection of DGU, which is subject to the voltage, current and power flow constraints as shown below:

$$\begin{aligned} &\textit{Maximizef} = \max \cdot \left(\Delta P^{R}_{Loss} + \Delta P^{DG}_{Loss}\right) \\ &\textit{Subjected to } V_{\min} \le |V_k| \le V_{\max} \\ &\textit{and } \left|I_{k,k+1}\right| \le \left|I_{k,k+1,\max}\right| \\ &\sum_{k=1}^{n} P_{GK} \le \sum_{k=1}^{n} \left(P_k + P_{Loss,k}\right). \end{aligned} \tag{3.1}$$

3.2. Power flow equations

Power flows in a distributed system are calculated by using the following set of simplified recursive equations which are used to calculate the real and reactive power flows for finding the power losses

$$\begin{aligned} P_{k+1} &= P_k - P_{Loss,k} - P_{L,k+1} \\ &= P_k - \frac{R_k}{\left|V_k^2\right|}\left\{P_k^2 + \left(Q_k + Y_k\left|V_k^2\right|^2\right)^2\right\} - P_{Lk+1} \\ Q_{k+1} &= Q_k - Q_{Loss,k} - Q_{L,k+1} \\ &= Q_k - \frac{X_k}{\left|V_k^2\right|}\left\{P_k^2 + \left(Q_k + Y_{k1}\left|V_k^2\right|^2\right)^2\right\} - Y_{k1}\left|V_k^2\right| \\ &\quad - Y_{k2}\left|V_{k+1}^2\right| - Q_{Lk+1} \end{aligned} \tag{3.2}$$

$$\begin{aligned} \left|V_{k+1}^2\right| &= \left|V_k^2\right| + \frac{R_k^2 + X_k^2}{|V_k|^2}\left(P_k^2 + Q_k^2\right) - 2\left(R_k P_k + X_k Q_k\right) \\ &= \left|V_k^2\right| + \frac{R_k^2 + X_k^2}{|V_k|^2}\left(P_k^2 + Q_k^2\right) - \left(Q_k + Y_k\left|V_k^2\right|^2\right) \\ &\quad - 2\left(R_k P_k + X_k\left(Q_k + Y_k V_k^2\right)\right). \end{aligned} \tag{3.3}$$

The calculation of the power loss in the line section connecting buses k and $k+1$ is given by

$$P_{Loss}\left(k, k+1\right) = R_k \cdot \left(\frac{P_k^2 + Q_k^2}{\left|V_k^2\right|}\right). \tag{3.4}$$

The power loss of the feeder, $P_{T,Loss}$ may be calculated by adding the losses of all line sections of the feeder, which is

$$P_{T,Loss} = \sum_{k=1}^{N} P_{Loss}\left(k, k+1\right). \tag{3.5}$$

3.3. Power loss using network reconfiguration

The use of reconfiguration in a radial distribution network is to identify a best configuration which can give a minimum power loss without violating the operation constraints. The operating