Electrical Power and Energy Systems 62 (2014) 855–861

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Transmission dispatch for loss minimisation using linearised power flow equations in mixed integer programming

Tajudeen H. Sikiru [a,b,*], Adisa A. Jimoh [a], Yskandar Hamam [c], Yasser Alayli [b], John T. Agee [a]

[a] Department of Electrical Engineering, Tshwane University of Technology, South Africa
[b] LISV of The University of Versailles Saint-Quentin-en-Yvelines, France
[c] ESIEE Paris, France and F'SATI at Tshwane University of Technology, South Africa

ARTICLE INFO

Article history:
Received 24 September 2013
Received in revised form 14 May 2014
Accepted 27 May 2014
Available online 19 June 2014

Keywords:
Transmission dispatch
Transmission line switching
Active power loss minimisation
Mixed integer programming
Linearised power flow equations

ABSTRACT

Transmission dispatch is a nonlinear optimisation problem due to the nonlinearity of the power flow equations. In the open literature, linearisation of power flow that yields only the active power is used for transmission dispatch problems. The solutions obtained are unacceptable when verified in nonlinear power flow equations, especially for smart grid applications because of the instability issues that result from such formulations. This paper overcomes this limitation by proposing a model that accounts for both active and reactive power in transmission dispatch problem formulations. Furthermore, this paper develops new formulations for transmission dispatch that covers the overall spectrum of operation of a power system network based on the load duration curve rather than the single period considered in the open literature. Transmission dispatch is considered in the context of minimising active power losses in this paper. The advantage of the proposed approach is that it gives acceptable results when verified with nonlinear power flow compared to the classical approach used in transmission dispatch problems. Also, the paper demonstrates that the global set of switchable lines that can minimise the active power losses of a network is obtainable from the multi-period formulations based on the consideration of varying load levels. The results indicate that only this set of switchable lines can reduce losses and ensure the stability of a network, hence useful for smart grid applications.

Introduction

Traditionally, transmission networks serve the purpose of transporting power from generating stations to load centres. This necessitates that a sufficient number of redundant lines are built into a power network to ensure continual operation of the network even when outages occur. These additional lines increase the active power loss that the network may incur. As loads vary, the statically designed network may not function optimally because of the changes in the operating conditions of the network. To overcome this limitation, Bacher and Glavitsch [1] proposed a topological restructuring of power system networks based on transmission line switching. It was further highlighted by Bacher and Glavitsch [2] that the topological restructuring of a network could be used to improve the operational characteristics of power system networks. Müller and Quintana [3] demonstrated that network restructuring could benefit power system networks by eliminating overload and voltage violation problems. In the same vein, Lobato et al. [4] proposed switching transmission lines based on a mixed integer linear programming technique. The DC power flow was incorporated as a constraint of the objective function in order to evaluate the effectiveness of the proposed method.

Other works carried out in this area include those by Shao and Vittal [5]. Granelli et al. [6,7] illustrated that changing the network topology in a power system could relieve line overloads, remove voltage violations and reduce loop flows, which are major obstacles in the deregulated market. Sikiru et al. [8] proposed transmission network reconfiguration to minimise active power losses based on the inherent structural properties of power system networks [9–12]. The inherent structural properties of power system networks are obtained from the eigenvalue decomposition of the Y-admittance matrix. Hence, providing a fast solution to power system problems based on the physics that governs power flow [9].

The issue of economic benefits of transmission line switching in a deregulated market was proposed by O'Neill et al. [13]. Co-optimising generator schedules with a changing network structure

* Corresponding author at: Department of Electrical Engineering, Tshwane University of Technology, South Africa. Tel.: +27 762090587.

E-mail addresses: sikiruth@tut.ac.za (T.H. Sikiru), jimohaa@tut.ac.za (A.A. Jimoh), hamama@tut.ac.za (Y. Hamam), alayli@uvsq.fr (Y. Alayli), ageejt@tut.ac.za (J.T. Agee).

http://dx.doi.org/10.1016/j.ijepes.2014.05.043
0142-0615/

Nomenclature

i_k	current of line k	C_g	incidence matrix of generator buses
r_k	resistance of line k	p_g	active power of generator
S_k	apparent power of line k	q_g	reactive power of generator
p_k	active power of line k	p_d	active power of load
q_k	reactive power of line k	q_d	reactive power of load
v	voltage magnitude	λ	loadability margin
θ	phase angle	x_k	discrete value of a line
B_k	susceptance of line k	t	individual period
G_k	conductance of line k	T	total period
C	incidence matrix of load buses	M	large scalar value

was demonstrated by Fisher et al. [14] and Hedman et al. [15] to increase the profitability margin in a deregulated market. Based on the successes recorded with the transmission dispatch from an economic perspective, Hedman et al. [16] highlighted that transmission dispatch is a useful tool in the smart grid application. The realisation that transmission assets play a critical role in the smart grid application has changed the perception about the static nature of transmission networks [17]. Transmission networks must be flexible to be useful and applicable in an intelligent sense. Hence, a full application of the smart grid concept could only be achieved if the transmission network is flexible.

The flexibility of transmission networks depends on the determination of switchable lines that would not compromise the security of the network. The previous works mentioned above used the mixed integer linear programming approach based on the linearised power flow that provides only the active power of the network. The use of only active power in transmission dispatch problem [18–20] causes enormous error in power system studies, especially in transmission dispatch problems where the reactive power plays a critical role [18,21,22]. The stability of a network is directly related to the reactive power sufficiency in a network [23,24]; this critical consideration is lost when only the active power of the network is used in the problem formulation of a network [18,22]. This paper overcomes this limitation by proposing a model that provides both the active and reactive power to ensure the stability of the network. Furthermore, previous research only considers a specific loading level (i.e. a single period) in transmission dispatch formulations, this is unacceptable because as loads vary, the operating conditions of the network changes. Hence, this paper proposes a transmission dispatch formulation that covers the overall spectrum of operation in a power system network using the load duration curve to overcome this limitation. This proposed multi period formulation provides a set of switchable lines that are suitable in stability issues for the different operation conditions encounter in realistic power system networks. The single period transmission dispatch previously available in the open literature is a particular solution of the more generalised formulation set forth in this paper. Hence, the results show that the multi period formulation is more benefitting to smart grid applications rather than the single period formulation considered in previous studies.

Transmission dispatch is considered in the context of minimising active power losses in this paper. The focus is primarily to identify the switchable lines that could minimise the active power losses without undermining the security of the network when compared with the AC nonlinear power flow equations. Multiple load variations were used to determine the lines that could be removed from service without compromising the network security. The mixed integer programming formulations that accounts for these load variations based on minimising the active power losses in a network for both the classical and the proposed linearisation are presented in 'Problem formulation for transmission dispatch'. The results of these linearisation approaches are presented in 'Results and discussion' along with discussions of their implications for practical networks. Finally, 'Conclusion' concludes the paper.

Problem formulation for transmission dispatch

Loads vary continuously in power system networks. In order to accounts for such variations, multiple snapshots of the network operating conditions must be captured in the problem formulation. The load duration curve gives an indication of the varying nature of loads and as such represents the power consumption pattern in a given power network. Multiple snapshots of the load duration curve may be incorporated in the problem formulation, which in this work is referred to as the multi period scenario. In the open literature, reported works were based on a single load level (i.e. single period formulation) [14,15,18,20,25]. Single period formulation does not cover the overall spectrum of a power system operational conditions, hence, it over simplifies the operating behaviour of a realistic network. A network experiences varying degree of load variation on a daily, monthly and annually bases. These variations are captured by the load duration curve and are integrated in the proposed multi period transmission dispatch formulation developed in this paper. Therefore, in order to determine the set of switchable lines that can minimise the active power losses for the varying nature of loads in the network, the multiple snapshots of the network loading levels are required. Hence, this approach yields the global set of lines that may be removed from service to minimise the active power loss of the network without compromising the security of the network.

In this section, a generalised multi period problem formulation for transmission dispatch based on the nonlinear power flow is presented first. The difficulty of solving this nonlinear problem [22] necessitates the need for the linearisation of the power flow equations. The classical linearisation approach for transmission dispatch problem is presented next in this section. The disadvantage of using such formulation for transmission switching problems is that important information regarding the reactive power of the network which is responsible for stability related problems is lost. The danger of ignoring such information is catastrophic in real network and highlighted in the next section. Also presented in this section, is the multi period formulation for the proposed linearisation approach. It should be noted that the single period formulations used in previous researches in transmission dispatch problems is a particular case of the generalised multi period formulations proposed in this paper. The proposed multi period formulations yield significant advantages in reducing losses and selecting the optimal lines to be switched which are beneficial in implementing smart grid.