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Security constrained optimal power flow solution of wind-thermal generation system using modified bacteria foraging algorithm

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ABSTRACT

In this work the variability of WP (wind power) has been suitably modelled and incorporated with the thermal generating units. The goal is to operate the wind-thermal generation system in a cost effective manner while maintaining a voltage secure operation with reduction in system loss. These objectives have been formulated in an OPF (optimal power flow) framework. As the wind generation cost model is subjected to intermittent WP, the voltage security aspect is considered during both *UE* (under estimation) and *OE* (over estimation) of available WP. This is achieved by suitably incorporating shunt facts devices (STATCOM) to provide reactive power (Q) support during *UE* scenario and maintaining a spinning reserve of thermal generators during *OE* scenario. To further utilize the *Q*-support, the DFIG (doubly fed induction generators) are used in the wind turbine. The combinations of optimum operational paradigms are obtained by optimizing the objective function with ACO (ant colony optimization) and MBFA (modified bacteria foraging algorithm). Finally, after performing several tests the superiority of MBFA optimized scenario over ACO is revealed so that the IEEE30-bus system operates in a voltage secured manner when subjected to N-1 contingencies.

1. Introduction

To fulfil the ever increasing power demand, attention is focussed on production of power from cleaner and environmental friendly non conventional power sources. In this regards wind power generation and integration have proven to be one of the most economic and established renewable energy technologies. The nature of intermittency of wind flow makes the scheduling of both conventional and wind powered units in a wind integrated system, a complex and challenging task. With improper estimation of an uncertain wind power, additional cost components needs to be incorporated to the generation cost during *UE* (under estimation) and *OE* (over estimation) of available *WP* respectively [1]. Economic and environmental issues based multi objective OPF (optimal power flow) of conventional generation systems with meta-heuristics algorithm is presented in Ref. [2]. Authors in Refs. [3–6] have considered the various cost components which are used in power systems with wind penetration. Moreover, with high penetration level of wind power, improper management and limited supply of reactive power resources may make the system voltage insecure during operational stages. Recently, the same authors as this work have followed similar wind variability model as discussed above to obtain an optimal generation schedule considering the physical limitation of reactive power capability of WECS units based on DFIG (doubly fed induction generators) [7]. With more and more DFIG based WECS units having limited reactive power generating capacities [8,9] operating in the system, it may be forced to run in a voltage insecure manner, particularly when the system is overloaded and stressed. Hence, it may be imperative to give local reactive power support at the DFIG buses and at various weak nodes in the network. Conventionally, apart from fixed capacitors reactive power supplying capacity, the role of shunt FACTS devices like static VAR compensators (SVC) and STATCOM have been extensively investigated [10,11,13]. STATCOM has been found to be more beneficial compared to SVC, as it has better operational flexibility towards improving the dynamic performance of the system, giving better reactive power support [14] and enhancing the LVRT (low voltage ride through) capability of wind farm [15]. STATCOM has been extensively utilized to achieve wide range of objectives like rapid voltage control [16], damping of the oscillations [17] and improving the loading margin [18,19] in power system. Therefore, with more and more wind penetration in the

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system that is prone to static voltage instability due to limited reactive power capacities of WECS (wind energy conversion systems), an investigation into the role of operational capacities of STATCOM can be beneficial.

Probing into the reactive power capabilities of DFIG based WECS, the authors in Ref. [20] have shown that during under evaluation of wind power, the reactive power (Q) capability of DFIG may limit the system's ability to maintain nominal grid bus voltage. To address the security concerns in the system, the authors have formulated a security constrained economic dispatch in DFIG based WECS where reactive power capability of DFIG has been analyzed. Few more works have considered the reactive power capability of DFIG converters [21,22].

In addition to the aspects discussed in Refs. [20–22], this proposed work which is an extension of [7] by the same authors, has attempted to validate the role of shunt FACTS device like STATCOM and local reactive power (Q) generating sources to obtain an optimum real power generation schedule using intelligent techniques like MBFA and ACO from both thermal and wind based units, so that the system can be operated in a voltage secure manner. A STATCOM is placed at the weakest bus in the test system [23]. The problem is formulated in an OPF framework [1] with an objective to minimize the generation cost of both types of generators. Following similar approach as in Ref. [7], additional cost components related to total reactive power requirement (C_{VS}) by the system for secure operation, which is to be supplied by either local Q-generating sources at WECS buses or STATCOM or both of them, is added. In OPF, the inclusion and impact of these additional factors on the system parameters has been analysed under different scenarios. OPF problems, when formulated in the optimization domain, have been extensively solved by several conventional and intelligent technique based algorithms [25–29]. In this work, suitably formulated objective functions are optimized with the help of ACO [26] and MBFA [28]. The optimized generating schedules are tested for their competence in obtaining a secure power system operation, when the system is subjected to numbers of (*N-1*) contingencies in the form of line outages, load increase and combination of line outage with load increase. Simulations are carried out in MATLAB/SIMULINK environment.

The unique contributions of this work are given as:

- Implementation of MBFA and ACO algorithm is validated in an existing IEEE 30 bus power system in a multi objective OPF framework with wind integration.
- The OPF formulation has incorporated the modeling issues related to stochastic variation of wind power and focuses attention towards the necessity of inclusion of shunt FACTS devices into the OPF framework.
- In this context the STATCOM is incorporated in the proposed system to overcome the limited Q support capability of DFIG there by meeting the severe voltage stability problems during *UE* scenario and stressed operating conditions.
- The voltage security aspect of the proposed wind–thermal generation system is analyzed by considering the system operation with different types and multiple stress levels.
- The effect of optimal generation scheduling on system performance is evaluated by MBFA and ACO while considering different operating scenarios.

The paper has been organized in the following manner. The main problem has been formulated in section 2. The wind variability and capability of reactive power in DFIG integrated WECS have been discussed in Section 3 and incorporation of STATCOM in the considered system has been dealt in Section 4. A brief overview of ACO and MBFA technique applied in this study has been presented in Section 5. In section 6, procedural details of simulations and results have been presented. In the same section few pertinent observations are made regarding the results obtained which has led to the conclusion in section 7.

2. Problem formulation

2.1. Problem

The random behaviour of wind power generation makes the scheduling problem more complex and thus introduces severe threat to power system operation. In this context, to model the *UE* and *OE* scenario in the scheduling horizon, the system should incorporate additional cost that can mitigate the power imbalance. As cited earlier, the limited capacity of reactive power of DFIG warrants additional reactive power support at the WECS buses to maintain a satisfactory voltage profile. The additional requirement of reactive power at the DFIG buses is considered to be supplied by external means like static capacitors. Along with this, to bring improvement in the voltage profile of the system more effectively, shunt facts devices like STATCOM are used. To visualize its effect more prominently in supplying the deficient reactive power, it is installed at the weakest bus [23] of the test system. An additional cost [12] due to the installation of new shunt facts device (STATCOM) is defined and added to the total cost. The operational efficiency of STATCOM is verified in two different scenarios i.e. with Q support at the DFIG buses and without any such support. As the inclusion of these additional costs may turn out to be uneconomical, a pragmatic decision on operational cost of Q supporting resources can be made by considering those in the cost function. Considering this aspect, two types of objective functions are formulated as presented in (1) and (2) respectively. An additional cost C_{VS2}, which corresponds to the cost of additional reactive power resources is added in F_2 unlike in F_1. The problem is formulated in the following way where the modelling and notations are similar to the previous work [7], by the same authors, which are reviewed for the sake of continuity. The optimization problem is explained as follows.

Minimize

$$F_1 = \sum_{t}^{N_g} C_t(P_{gt}) + \sum_{r}^{N_w} [C_{wr}(P_{wr}) + C_{p,wr}(P_{wr,av} - P_{wr}) + C_{r,wr}(P_{wr} - P_{wr,av})] + Pf_1 + Pf_2 + C_{VS1} \quad (1)$$

Minimize

$$F_2 = \sum_{C_t(P_{gt})}^{N_g} C_t(P_{gt}) + \sum_{r}^{N_w} [C_{wr}(P_{wr}) + C_{P,wr}(P_{wr,av} - P_{wr}) + C_{R,wr}(P_{wr} - P_{wr,av})] + Pf_1 + Pf_2 + C_{VS2} \quad (2)$$

Subject to constraints:

$$\sum_{t}^{N_g} P_{gt} + \sum_{r}^{N_w} P_{wr} = P_{loss} + P_{load} \quad (3)$$

$$\sum_{t}^{N_g} Q_{gt} + \sum_{r}^{N_w} Q_{wr} = Q_{loss} + Q_{load} \quad (4)$$

$$P_{gt}^{min} \le P_{gt} \le P_{gt}^{max} \quad (5)$$