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Impact of wind uncertainty, plug-in-electric vehicles and demand response program on transmission network expansion planning

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ABSTRACT

The aim of this paper is to minimize the total cost of the system by incorporating wind power and plug-in-electric vehicles (PEVs) along with demand response (DR) program. The methodologies have proposed in contrast with the conventional algorithm in which the transmission line investment cost has been minimized without considering the dynamism of the deregulated environment. Moreover, the transmission network planning enhances the competitiveness of the power market, where more market players can participate. In this situation, the network planner has an important role in assessing the needs for transmission investments. Now-a-days practice of the network planner is to utilize more renewable power resources, PEVs and implementation of different electricity price tariffs. To achieve more benefits of PEVs and wind energy, their optimal utilization is a major concern. This paper proposes a mathematical model for solving the combined effect of PEVs and wind power integration with incentive-based DR program on static transmission network expansion planning (STNEP) problem. To solve this non-linear and non-convex problem, a nature-inspired optimization algorithm named gbest-guided artificial bee colony algorithm (GABC) is applied due to its robustness. The algorithm's performance is evaluated through modified IEEE 24-bus, Brazilian 46-bus and Colombian 93-bus system. The test results indicate that the combined effect of DR, PEVs and wind has reduced the total system cost significantly.

Introduction

Economic benefits and environmental issues are the two major concerns of the power system planning and its operations. Several strategies such as integration of renewable energy resources are adopted by the network planner to overcome these problems [1,2]. As there are limitations of conventional energy resources, major attraction is moving towards the renewable power resources and other portable power devices. The power system planning is to be done in an optimized way to prevent the system failure, load shedding and reliability. However, the transmission expansion planning (TEP) has an important role to play, as it helps to find out the new transmission facilities required. TEP determines "what," "where", and "when" new transmission facilities to be installed to the system requirements. Transmission network expansion planning (TNEP) is categorized as static or dynamic TNEP problems. The static TNEP problem is a single period planning, whereas the dynamic TNEP is a multi-period planning [3].

Since 1970's TNEP problem has been solved as an optimization problem [4]. Thereafter many researchers have worked to solve the TEP problem by applying various techniques and the research done so far on TEP problem has been reported in [1,2]. Starting from the classical optimization methods [4–6], heuristic methods [7–9] and population/or nature inspired algorithms [10–18] have been applied to solve TEP problem.

Generally big vulnerability comes in finding "optimal solution" by mathematical optimization methods due to the internal limitations of the optimization techniques itself, such as the presence of non-linearity and stochastic modeling. Furthermore, this leads to large computational burden to the TEP planner. Therefore, these days heuristic and meta-heuristic techniques are used to solve TEP problems, which provide fast convergence and rapid calculation.

In the literature various issues and difficulties related to TEP problems have been reported in [13,15–17]. In [13], the multiyear TEP problem has been solved by considering demand uncertainty nature to find out the most suitable group of projects, as well as their scheduling along with the planning horizon. In [15], the TEP problem has been solved by considering security issue and the changes in the network configuration and affects in the investment cost during any line outage has been presented. The multi-stage

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Nomenclature

A_i^j	incentive price paid to the consumer in jth load period (US \$/MW)
$B\left(d_i^j\right)$	customer's income in the jth load period (US)
$a_i,\ b_i,\ c_i,\ d_i,\ e_i$	cost coefficient of the ith generator
c	scale factor (units of wind speed)
C_{DRj}	cost of demand response for jth load period (US \$)
$C_{Lik}(\cdot)$	cost function of new line added to the $i-k$ right-of-ways (US \$)
$C_i(\cdot)$	total fuel cost function of the ith generator (US \$/h)
$C_{PEVi}(\cdot)$	cost function of total number of vehicle connected to bus i (US \$)
$C_{wdi}(\cdot)$	direct cost function of ith wind farm (US \$/h)
$C_{pwi}(\cdot)$ and $C_{rwi}(\cdot)$	underestimation and overestimation cost functions of the ith wind farm (US \$/h)
d_{wi}	direct cost coefficient for the ith wind farm (US \$/MW h)
$d_{o_i}^j$ and d_i^j	new load demand and initial load demand at bus i for jth load level (MW)
CDR	cost of demand response participation (US \$)
TWC	total wind power utilization cost (US S/h)
E_i^j	elasticity of jth load level with respect to ith bus
ECV	energy cost of the PEV
F	fitness function
FC	fuel cost (US \$/h)
f_{ik}^j	active power flow in the $i-k$ branch for jth load level (MW)
$f_V(v)$ and $F_V(v)$	weibull probability and cumulative distribution function (CDF) density function
f_{ik}^{max}	active power flow limit on the $i-k$ branch (MW)
$f_W(P_w)$	WECS wind power pdf
TLC	transmission line investment cost (US \$)
k	shape factor
k_{pi} and k_{ri}	underestimation and overestimation cost coefficient for the ith wind farm (US \$/MW h)
L_d	number of load levels
n_{ik}^o and n_{ik}^j	initial number of lines and new lines added jth load level to the $i-k$ branch
n_{ik}^{max}	maximum number of lines that can be added to the $i-k$ branch
N_{lk}	set of lines connected to bus k
N_{PEV}^{max}	maximum number of PEVs
$N_v,\ N_g$ and N_w	number of PEVs, thermal generators and wind farms
pen_i^j	penalty at bus i for jth load level (US \$/MW)
P_{gi}^j	active power generation at the ith bus at load level j (MW)
$P_{inc}\left(\Delta d_i^j\right)$	total payment for incentive (US \$)
$PEN\left(\Delta d_i^j\right)$	total payment for penalty (US \$)
P_{gi}^{min} and P_{gi}^{max}	active power generation lower and upper limit at the ith bus (MW)
P_{dk}^j	active load at bus k for load level j (MW)
P_{PEVi}^j	power generated by the vehicle connected to bus i at load level j (MW)
P_{wi}^j	scheduled wind power from the ith wind farm at load level j (MW)
$P_{wi,av}^j$	available wind power from the ith wind farm at load level j (MW)
P_{wr} and P_w	rated wind power and output power of the ith wind farm (MW)
$Prob\{\cdot\}$	probability of events
TC	total cost (US \$)
$v,\ v_{ci},\ v_{co}$ and v_r	wind speed, cut-in, cut-out and rated wind speed m/s
γ_{ik}	susceptance of a branch between buses $i-k$
θ_m^j and θ_n^j	phase angle at buses m and n for load level j (rad)
$\rho_{o_i}^j$ and ρ_i^j	original electricity and spot electricity prices at bus i for jth load (US \$/MW h) level (US \$/MW h)
Ω	set of all candidate lines

TEP problem in a deregulated electricity market has been presented. The objective is to minimize the investment and operating costs with the inclusion of $N-1$ reliability criterion [16]. In [17], the impact of distributed generation (DG) on sub-transmission system expansion planning has been presented, which gives the details about the optimal location and capacity of the substation and DGs.

The wind related issues on TEP problem has been reported in [19–23]. In [19], the reliability issue considering large wind farm and load uncertainty has been described. The analyses described the maximum wind energy capacity that is penetrated to a specified place. The impacts of large-scale wind integration have been solved by taking investment, risk and congestion costs, reserve market and reserve availability costs, and wind power investment cost in [20–23]. The security and reliability constraints have been considered to minimize the system cost. However, none of the mentioned references includes the wind power utilization cost, underestimation cost, overestimation cost and the optimal placement of wind turbine on TNEP problem so far.

In a competitive electricity market, new incentive policy influences the consumers to take more participation in DR programs. DR can be defined as the changes in electricity consumption patterns by the end-user customers, according to the changes in the price of electricity over a period of time from their normal usage patterns [24]. Implementation of DR program is found as an alternative to generation and transmission expansion [25]. Demand response (DR) programs have been widely studied in unit commitment (UC) problem some of the papers are in [26–29]. In [26,27], two types of DR programs have been reported, and their impacts on load shape, load level, and benefits to the customer have been analyzed. DR scheduling by a stochastic model for security-constrained UC in the wholesale electricity market has been solved, and the benefits of demand-side reserve in electricity markets has been presented in [28,29]. From the literature reviewed, it has been found that only few researchers have reported the implementation of DR programs for TEP problem [30,31]. In [30], TEP problem has been solved by incorporation of demand response schedule considering wind power penetration. In [31], a price-based DR program has been implemented on the TEP problem. However, in both the papers the objective is to minimize the total cost of the system, but the detail related to the minimized value of cost, transmission line configuration and the impact on load demand have not been adopted.

According to the electric power research institute (EPRI), it is expected that by 2020 up to 35% of the total vehicles in the U.S. will be PEVs [32]. The PEVs either in the form of source as a vehicle to grid (V2G) technology or load as a grid to vehicle (G2V) technology studies in the different fields of the power systems have been reported in the literature recently [33–42]. The proper scheduling of PEVs prevents overloading of the network, which leads to the congestion free operation. The researches have studied the applications of PEVs on the distribution network [33–35], UC problem [36], economic load dispatch problem [37–39] and transmission network [40–42].