Optimal Location-Allocation of TCSC Devices on a Transmission Network

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***Abstract*—Installing a thyristor controlled series capacitor (TCSC) device on a transmission network reduces network congestion and generation cost. We formulate the TCSC location-allocation problem as a mixed integer nonlinear program, and propose a novel decomposition procedure for determining the optimal location of TCSCs and their respective size for a network. The load uncertainty, AC characteristic of transmission lines, and nonlinear cost of TCSCs explicitly are considered. The results of applying the procedure to the IEEE 118-bus test system are reported, and insights into the TCSC location-allocation problem are provided.**

***Index Terms*—Transmission network, TCSC location-allocation, Benders' decomposition, reactive power balance.**

NOMENCLATURE

1) Sets and Indices:

Ω_M Set of all buses (nodes).

m, n Bus (node) index. n is an alias of m.

N_b Number of buses ($|\Omega_M| = N_b$).

Ω_L Set of all transmission lines.

$\Omega_{L_{mn}}$ Set of transmission lines connecting buses m and n.

l Transmission line index.

N_l Number of transmission lines ($|\Omega_L| = N_l$).

Ω_K Set of all generators.

Ω_{K_m} Set of all generators located at bus m.

k Generator index.

N_k Number of generators ($|\Omega_K| = N_k$).

Ω_D Set of all demands.

Ω_{D_m} Set of all demands located at bus m.

d Demand index.

Ω_S Set of all scenarios.

ω Scenario index.

2) Variables:

θ_m Voltage angle at bus m.

v_m Voltage magnitude at bus m.

p_k, q_k Active and reactive power supplied by generator k.

$\Delta_k^{p^+}$, $\Delta_k^{p^-}$ Non-negative slack variables pertaining to active power of generator k in the sub-program.

$\Delta_k^{q^+}$, $\Delta_k^{q^-}$ Non-negative slack variables pertaining to reactive power of generator k in the sub-program.

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$\Delta_m^{v^+}$, $\Delta_m^{v^-}$ Non-negative slack variables pertaining to voltage of bus m in the sub-program.

λ_{mnl}, γ_{mnl} compensation level of susceptance and reactance of transmission line l connected to buses m and n.

u_{mnl} Binary variable denoting the placement of TCSC on line l between buses m and n.

μ_l, α_k Dual variables attained in sub-program.

Φ^{TCSC} Cost of installed TCSCs in the system.

π_{mnl}^{TCSC} Amortized cost of TCSC installed on line l connected to buses m and n.

S_{mnl}^{TCSC} TCSC operating point in MVar (installed in line l between buses m and n).

3) Parameters:

c_k Cost coefficient of generator k.

p_d, q_d Active and reactive power demand.

r_{mnl} Resistance of transmission line l connected to buses m and n.

x_{mnl} Reactance of transmission line l connected to buses m and n.

$x_{mnl}^{'}$ Reactance of transmission line l after compensation.

p_k^{min} ,p_k^{max} Lower and upper bound of active power supplied by generator k.

q_k^{min} ,q_k^{max} Lower and upper bound of reactive power supplied by generator k.

θ_m^{min}, θ_m^{max} Lower and upper bound of voltage angle at bus m.

v_m^{min}, v_m^{max} Lower and upper bound of voltage magnitude at bus m.

λ^{max} Maximum available compensation level.

η Number of available TCSCs.

s_{mnl}^{st} Stability limit of line l connected to buses m and n.

s_{mnl}^{th} Thermal limit of line l connected to buses m and n.

CRF The capital recovery factor.

ir The interest rate percentage/year.

LT The lifespan of TCSC device in years.

φ_ω Load factor of scenario ω.

ψ^v, ψ^q Penalty terms associated with voltage and reactive power slack variables, respectively.

4) Functions:

$p_{mnl}(.)$ Active power flows from bus m to bus n through transmission line l.

$q_{mnl}(.)$ Reactive power flows from bus m to bus n through transmission line l.

$s_{mnl}(.)$ Apparent power flows from bus m to bus n through transmission line l.