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Pareto-efficient double auction power transactions for economic reactive power dispatch

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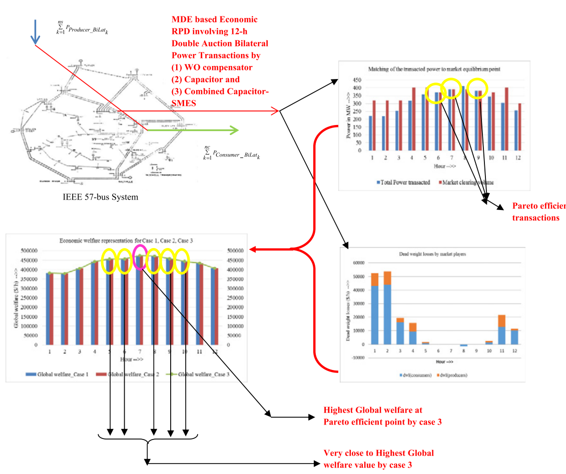
HIGHLIGHTS

- SMES for the economic RPD and dynamic voltage stability analysis.
- Planned bidding.
- Pareto efficient global welfare.

GRAPHICAL ABSTRACT



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ABSTRACT

Pareto-efficient 12-h variable double auction bilateral power transactions have been considered here. Effect of such on the economic welfare is observed while solving the reactive power dispatch (RPD) by differential evolution with random localization technique. This has been accomplished by a combination of static and dynamic *var* compensators like capacitor and superconducting magnetic energy storage (SMES) considering the IEEE 57-bus network. Out of these 12-h variable power transactions, the Pareto efficient transactions which were reconciled by planed biding, have provided the maximum global welfare. The economics were ascertained by cumulating the net benefits of the market players and the reduced merchandising surplus caused by the *var* compensators. The combined capacitor–SMES based Pareto efficient observations on economic RPD were able to reduce 7.41% more power loss and 2.5 times improved economic benefit over the singular capacitor placement. This further achieved 0.069% profit enhancement in connection to the fundamental global welfare.

1. Introduction

One of the emerging issues of the deregulated power scenario is reactive power dispatch (RPD) with bilateral power transactions

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Nomenclature

C_Surplus	the individual consumer's surplus ($/h)
P_Profit	the individual producer's profit ($/h)
(*C_Surplus* + *P_Profit*)	the fundamental global welfare ($/h)
ns, *nc*	number of suppliers and consumers
$NMB_{Capacitor}$	the net monetary benefit by capacitors ($/h)
Inc	incentive due to power loss compensation in ($/MW h)
P_{LOSS_bVCP}	the power loss occurred without respective *var* compensators (MW)
P_{LOSS_aVCP}	the power loss occurred with respective *var* compensators (MW)
$HIC_{Capacitor}$	the operation and maintenance cost of the capacitor device ($/h)
$NMB_{Capacitor+SMES}$	the net monetary benefit by combined capacitor–SMES ($/h)
HIC_{SMES}	the installation and the operating cost of the SMES device ($/h)
C_{SMES}	the investment cost of the SMES coil and core ($)
Q_{SMES}	the reactive power from SMES (MVar)
$P_{BiLatLoss}$	real power loss due to bilateral power transactions (MW)
P_G	the total real power generations of the network (MW)
P_D	the total load demand of the network (MW)
P_{P_BiLat}	transacted power from producers (MW)
P_{C_BiLat}	transacted power from consumers (MW)
DWL_P	dead weight losses for producers ($/h)
V_i	voltage of the *i*th bus (p.u.)
V_j	voltage of the *j*th bus (p.u.)
$\Delta price$	the difference between the final offer price between the producer and consumer
nbus, *ng*	number of generator and load buses
Nc, *Ns*	number of buses for shunt capacitors and SMESs
δ_i	voltage angles of bus *i* (p.u.)
δ_j	voltage angles of bus *j* (p.u.)
G	the conductance of the network (p.u.)
B	the susceptance of the network (p.u.)
Q_{S_BiLat}	reactive power handled by the supplier during bilateral power transactions (MVar)
Q_{C_BiLat}	reactive power handled by the consumer during bilateral power transactions (MVar)
Q_D	the reactive power handled by load buses (Mvar)
Q_G	the reactive power handled by the generator buses (MVar)
P_{SMES}	the active power from SMES (MW)
Q_C	reactive power output of the capacitors (MVar)
V_{Coil}	the voltage across the coil of the SMES (p.u.)
I_{Coil}	the current flowing through SMES coil (p.u.)
L	the inductance of SMES coil (Henry)
E	energy of the SMES coil and core (MJ)
DWL_C	dead weight losses for consumers ($/h)

[1,2]. This type of transactions takes place in the backdrop of power exchange and allocation between the equal number of power producers and consumers in the presence of transaction authority [3,4]. This is also accomplished under certain rights and reservation of the utilities for a short term or long term period. In most of the centralized power pools, two types of bidding are considered. Amongst them the double auction bidding are mostly used where both the power suppliers and consumers submit their bid to the transaction authority. During the power transaction period, the Pareto efficient transactions provide the maximum benefits to the competent participants while satisfying the market equilibrium criteria [5,6]. Since the economics is one of the governing factors of the deregulated power scenario, the participants would expect to earn highest benefit in terms of Pareto efficient transaction. In this regards few factors like planned biding, the economics of *var* compensation, etc. have a great impact on the economic welfare of the system under consideration. In the context of *var* compensation, it is the essential means to solve the RPD problem in an efficient, reliable, economic and sustainable manner. The proposed RPD problem which is real power loss minimization aspect accomplishing dynamic voltage stability was frequently solved by the capacitive *var* compensators [2,7–13]. Many recent optimization methods [14–16] were also proposed to formulate the RPD issue as capacitive *var* compensator based reactive power planning problem. Besides the capacitive *var* compensators, few advanced *var* compensators [17] likely distributed generating (DG) units [18], flexible AC transmission (FACTs) controller [19], few energy storage systems as superconducting magnetic energy storage SMES [20] and some of their combinations [21] were also used in greater domain.

The advanced *var* compensators handled the deregulated power scenario based RPD issues to some extent although majority of them were focused on the technical issues without considering their economic impact to the system under considerations [22–27,17,28,29]. Since, economics is one of the prime objects of the deregulated power scenario; researches were further continued to derive the economic benefit of the advanced *var* compensations to the economic welfare of the present system [30–38]. These studies covered demand response for shielding financial risks, reduced merchandising surplus while adjusting the spot prices, profit maximization based on demand side management as well as social welfare maximization for small systems. However adequate economic solutions involving advanced *var* compensators satisfying Pareto efficiency for maximum benefit are sparse in literature. Therefore, the study on advanced *var* compensation based economic RPD in the backdrop of Pareto efficient bilateral power transactions draws a major attention in the present research work.

Differential evolution based power system optimization are gaining more interest these days [39–41]. Here, the modified differential evolutionary optimization technique based RPD problem involving 12-h variable double auction bilateral power transaction has been considered for the IEEE 57-bus network [42]. The observations in terms of loss minimization and dynamic voltage stability were proposed using advanced *var* compensator such as capacitor–SMES combination. Moreover, the observations by the proposed approach were compared w.r.t the case studies having no *var* compensators and singular capacitive *var* compensators. The economics of the *var* compensation were also obtained in the form of reduced merchandising surplus [6]. The impacts of reduced merchandising surplus were considered to improve the global welfare which have been further analyzed on the basis of Pareto efficient transactions [6]. In this context, bidding of the market participants of the bilateral transactions played an important role to determine the market clearing point as well as the global welfare. Moreover, the bidding of the participants helped to generate a clear idea on how to achieve Pareto efficient transactions to enhance the benefit. The proposed economic observations were also compared with the study having no *var* compensators or capacitive *var* compensator to allow presenting more clearly the significance of the proposed approach.

This rest of the presented study is described as follows: Section 2 explains the literature review to appreciate the latest findings and key challenges relating to the addressed issue in the present work, Section 3 delineates the economics of the power