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Improvement of the simultaneous active and reactive power markets pricing and structure

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Abstract: Reactive power markets have received special attention in recent years due to the importance of reactive power for maintaining network stability and freeing up the capacity of transmission lines. Hence, this study tries to improve this market and encourage fair competence in reactive electrical power generation through improving the unit pricing process. On the other hand, simultaneous active and reactive power markets are implemented by this study in order to account for energy market and reactive power market interactions. A new structure for paying lost opportunity costs to reactive power producers is presented here which is aimed for improving this market. Additionally, considering local nature of reactive power, the new method of holding simultaneous market using regional reactive power is proposed and pertaining results are compared with separate, non-local market. Finally, the effect of increments in prices proposed by effective units in reactive power market on implementation costs have been compared with separate and simultaneous markets, in order to investigate efficiency of active and reactive simultaneous markets.

List of symbols and acronyms

i, j	index number of buses
u	index number of generating units
NB	network total number of buses
NU_i	total number of generating units connected to bus i
m	total number of separate voltage control regions
$\rho_{\mathrm{p}}^{i,u}$	proposed marginal cost for generator to produce active power
$Q_{\max}$, $Q_{\min}$	maximum and minimum reactive powers proposed by a unit
$P_{\mathrm{G}}^{\max}$, $P_{\mathrm{G}}^{\min}$	maximum and minimum active powers produced by a unit
$P_{\mathrm{D}i}$, $Q_{\mathrm{D}i}$	active and reactive power demands at bus i
Y_{ij}	admittance between bus i and bus j
Θ_{ij}	angle of admittance
X_{s}	synchronous generator reactance
ρ_0	MCP for unit availability
ρ_1	MCP for loss cost in zone $(Q_{\min}, 0)$
ρ_2	MCP for loss cost in zone (Q_{base}, Q_A)
ρ_3	MCP for lost opportunity cost in zone (Q_A, Q_B)
$\rho_{0,r}$, $\rho_{1,r}$, $\rho_{2,r}$	clearing prices pertaining to a_0, m_1 and m_2 for zone r in SARPM
$\rho_{\mathrm{p(sep)}}^{\mathrm{MCP}}$	MCP of active power in separate active power market
$\rho_{\mathrm{p(MCP)}}$	MCP of active power in SARPM
$Q_{\mathrm{av_{max}}}$, $Q_{\mathrm{av_{min}}}$	maximum and minimum reactive powers available for a generating unit
$P_{\mathrm{G}}^{i,u}$, $Q_{\mathrm{G}}^{i,u}$	active and reactive powers generated by generator u connected to bus i
$P_{\mathrm{G(sep)}}^{i,u}$	active power generated by unit u connected to bus i in separate active power market
$P_{\mathrm{G(sim)}}^{i,u}$	active power generated by unit u connected to bus i in SARPM
$Q_{1G}^{i,u}$	reactive power provided by generating unit for absorbing reactive power in zone $(Q_{\min}, 0)$
$Q_{2G}^{i,u}$, $Q_{3G}^{i,u}$	reactive power generated by unit u connected to node i in zones (Q_{base}, Q_A) and (Q_A, Q_B)
$W_{\mathrm{P}}^{i,u}$, $W_0^{i,u}$	binary variables indicating that unit u connected to node i is selected to generate active and reactive powers
$W_1^{i,u}$, $W_2^{i,u}$, $W_3^{i,u}$	binary variables indicating that unit u connected to node i is selected to generate power in zones $(Q_{\min}, 0)$, (Q_{base}, Q_A), (Q_A, Q_B)
$\Phi_{\mathrm{sep}}^{i,u}$	profit from producing active power in unit u connected to node i in separate active power market
$\Phi_{\mathrm{sim}}^{i,u}$	profit from producing active power in unit u connected to node i in SARPM
$S_{i,j}$	power transmitted by line between bus i and bus j
V_j, δ_i	magnitude and angle of voltage at bus j
Q_{c}, Q_{v}	limited current and voltage of generating unit
Q_{u}	under-excitation zone for generating unit
V_{t}	generator's terminal voltage
I_{a}	armature static mode current
E_{af}	excitation voltage
δ	angle between terminal voltage and perpendicular axis of synchronous generator
$\mathrm{LOC}^{i,u}$	lost opportunity cost for unit u connected to node i
$\mathrm{VSM}^{\mathrm{desired}}$	minimum desired value for voltage stability margin (VSM) index

1 Introduction

A generator only can sell its active electrical power if sufficient reactive power exists in the system to maintain voltage levels within the acceptable ranges [1, 2]. Lack of reactive power could lead to voltage instability all over the network and cause voltage collapse [3]. Voltage collapse due to insufficient reactive power is known as the main reason of blackouts all over the world. For instance, power outage in 2 July 1996 in US west coast and 23 September 2003 in Sweden and Denmark were reported to be the consequences of voltage collapse [4]. A fair reactive power pricing system is necessary to encourage producers to participate in reactive power market. Therefore, several studies have recommended reactive power pricing as an important procedure in order to improve reactive power markets. Some examples are: pricing based on load power coefficient [1], modified admittance matrix [5], equalised pricing [6], and nodal pricing [7] schemes of reactive power. In this regard, reactive power generation costs assessment and minimisation methods are proposed as well [8, 9] in order to provide a comprehensive model for reactive power markets. Reference [2] represents the majority of new literature [10, 11] which have addressed reactive power production through paying an invariant amount to the units in compensation for being on standby to produce power. However, reference [2] has not calculated the real amount of losses due to losing opportunities for producing active power.

Interactions between active and reactive power components introduce challenges which impede improvements in separate power markets. Active and reactive power values are in relation through several concepts such as: load flow equations, network lines capacity limitations, and synchronous generator capability curves [12]. In this way, generators must reduce their active power production rate in order to produce reactive power in some working zones [2]. This causes it to shift out of optimum conditions of active power production. Therefore, generators usually do not desire to produce reactive power and request high prices for producing in some certain zones or refuse to produce reactive power at all [12]. As a result, participating generators in reactive market tend to ask for higher prices in turn and drag the market further away from a fair one.

In fact, the producer's location is a critical factor in reactive power price propositions. For example, a low-price proposition is not necessarily appealing if the provider is located in a bus far apart from consumption main point [13]. Therefore, reactive power pricing scheme as done in [6] is not much desirable. Local reactive power markets are proposed by various studies [14, 15] and their superiority over single-regional market is approved. Hence, location characteristics of reactive power producers need to be considered as a design factor in concept of simultaneous active and reactive power markets (SARPMs).

Considering the strong dependency of reactive power to the voltage, and the importance of reactive power provision in improving voltage stability indices, it is necessary to take voltage stability constraints in the proposed market model into account as well. On the other hand, another important challenge which electricity industry is facing today is to reduce the contaminating gases emission; this subject has received attention in several studies [16, 17]. Thus, a market should be implemented as a suitable solution for reducing the pollution in which environmental constraints are considered as well.

This paper tries to address the challenges in reactive power markets through the following implementations:

- A new model for availability cost price propositions as a term in reactive power cost function.
- A model of SARPM which uses a new method for lost opportunities cost (LOCs) calculation for each unit.
- Introducing a new SARPM structure which includes location characteristics of produced reactive power, while considering environmental and voltage stability limitations. Moreover, comparing the results to independent active/reactive power markets as well as SARPM with uniform pricing method.
- The effect of higher prices proposed by effective units in reactive power market on implementation costs is compared between separate and simultaneous type of markets in order to investigate efficiency of SARPM and its effect on decreasing the market strength.

This paper is presented in nine sections. Following Section 1, modifications in pricing structure of reactive power market are explained. Sections 4 and 5 present the models of separate as well as SARPMs, whereas some improvements are introduced which aim for upgrading LOC payment structure in SARPM. A simultaneous market is presented in Section 6 which considers reactive power as a function of producers' location as an important trait. The simultaneous market model including voltage stability constraints and pollution emission limits is presented in Section 7. Section 8 presents numerical studies on presented models using generalised algebraic modelling system (GAMS) optimisation software [18] tested on a 24 node IEEE reliability test system (RTS) network [19]. Conclusions and suggestions are presented in the last section.

2 Improving the pricing structure for reactive power

The idea in this study is to improve pricing scheme and modifying expected payment function (EPF) through changing reactive power market settlement which is discussed as follows. First, the EPF proposed in [2] is stated and then proposed modifications are presented.

2.1 Expected payment function

On the basis of reactive power capability of synchronous generator (Fig. 1), total cost of production for any generator is categorised by Zhong and Bhattacharya [2] into three parts: availability costs, implementation costs, and opportunity costs.

Generators present their proposed prices in reactive market as EPF which is given as [2]

$$\mathrm{EPF}_i = a_{0,i} + \int_{Q_{\min}}^{0} m_{1i}\,\mathrm{d}Q_i + \int_{Q_{\mathrm{base}}}^{Q_A} m_{2i}\,\mathrm{d}Q_i + \int_{Q_A}^{Q_B} (m_{3i}Q_i)\,\mathrm{d}Q_i \quad (1)$$

Coefficients in (1) indicate different components of reactive power production costs:

a_0: proposed availability price [dollars ($)].
m_1: proposed loss costs pertaining to working in under-excitation zone (reactive power absorption zone), $Q_{\min} \le Q \le 0$ in $/megavar (MVar)-h.
m_2: proposed price of loss costs for working at $Q_{\mathrm{base}} \le Q \le Q_A$ zone in $/MVar-h.
m_3Q: proposed price of opportunity costs for working at $Q_A \le Q \le Q_B$ zone in ($/MVar-h)/MVar-h (Proposed LOC is a function of output reactive power; consequently the EPF component would be a second-order function of Q.).

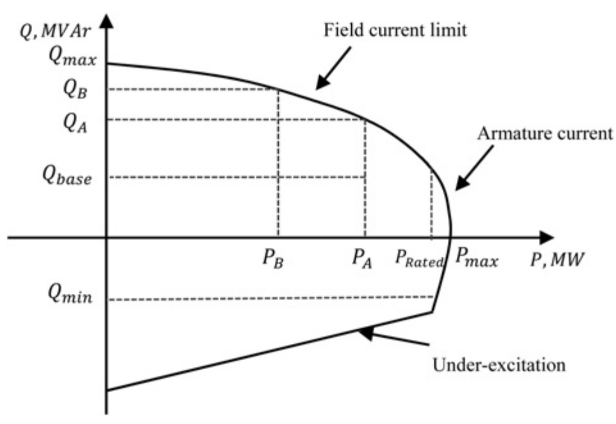

Fig. 1 *Synchronous generator capability curve*

2.2 Modified EPF

EPF proposed by Zhong and Bhattacharya [2] calculates availability cost (a_0) as being independent of available capacity of generator and measures it in \$, whereas units with higher available capacity are preferred by independent system operator (ISO) since higher available capacity ensures voltage safety further. Evidently, higher generator capacity would imply more costs as well. This paper proposes a pricing structure which states the availability costs for the generators as available capacity amount by \$/MVar-h instead of \$. An important point is that minimum and maximum reactive capacities a unit can offer are not exclusively determined by amounts proposed by it, but they are also limited by reactive power capability curves. The EPF would be modified as follows

$$\mathrm{EPF}_i = a_{0,i}\left(Q_{\mathrm{av}_{\max}} - Q_{\mathrm{av}_{\min}}\right) + \int_{Q_{\min}}^{0} m_{1i}\,\mathrm{d}Q_i + \int_{Q_{\mathrm{base}}}^{Q_A} m_{2i}\,\mathrm{d}Q_i + \int_{Q_A}^{Q_B} (m_{3i}Q_i)\,\mathrm{d}Q_i \tag{2}$$

$$Q_{\mathrm{av}_{\max}} = \min\{Q_{\mathrm{c}},\ Q_{\mathrm{v}},\ Q_{\max}\} \tag{3}$$

$$Q_{\mathrm{av}_{\min}} = \max\{Q_{\mathrm{u}},\ Q_{\min}\} \tag{4}$$

$$Q_{\mathrm{c}} = \sqrt{(V_{\mathrm{t}}I_{\mathrm{a}})^2 - (P_{\mathrm{G}})^2} \tag{5}$$

$$Q_{\mathrm{v}} = \sqrt{\left(\frac{V_{\mathrm{t}}E_{\mathrm{af}}}{X_{\mathrm{s}}}\right)^2 - (P_{\mathrm{G}})^2} - \frac{(V_{\mathrm{t}})^2}{X_{\mathrm{s}}} \tag{6}$$

$$Q_{\mathrm{u}} = \frac{P}{\tan\delta} - \frac{V_{\mathrm{t}}^2}{X_{\mathrm{s}}} \tag{7}$$

$(Q_{\mathrm{av}_{\max}} - Q_{\mathrm{av}_{\min}})$ term in (2) indicates reactive power capacity which generator can make available.

Constraint (3) ensures that maximum available capacity for a unit equals the minimum proposed reactive power available and the amount of available reactive power based on voltage and current limitations. Constraint (4) states that minimum available capacity for a unit equals maximum reactive power proposed by that unit and its amount of available reactive power based on under-excitation limitations. Q_{c} indicates current limit and Q_{v} indicates voltage limit here [20]. Q_{u} is the under-excitation zone [21]. $Q_{\max}$ and $Q_{\min}$ are maximum and minimum reactive power capacities declared by a unit.

3 Holding separate markets for active and reactive powers

3.1 Separate active power market

In concept of independent active market, all producing units make their propositions to offer certain amount of electrical energy at a certain price during designated time period and submit them to an ISO. The operator optimises the load flow using the objective function which minimises total cost, makes decision about their output in the market, and determines maximum accepted price as the market clearing price (MCP). Each selected unit would be paid according to MCP multiplied by its production volume. Hence, the objective function would be

$$\text{minimise}\left(\sum_{i=1}^{\mathrm{NB}}\sum_{u=1}^{\mathrm{NU}_i}\left(W_{\mathrm{P}}^{i,u}\rho_{\mathrm{P(MCP)}}P_{\mathrm{G}}^{i,u}\right)\right) \tag{8}$$

3.2 Separate reactive power market

The object here is to provide the network with required reactive power at minimum possible cost. Total payment function (TPF) as the objective function for optimal load flow problem in reactive power market clearing needs to be modified since EPF has been modified. The modified TPF is

$$\mathrm{TPF} = \sum_{i=1}^{\mathrm{NB}}\sum_{u=1}^{\mathrm{NU}_i}\left(\begin{array}{c} \rho_0 W_0^{i,u}\left(Q_{\mathrm{av}_{\max\mathrm{G}}}^{i,u} - Q_{\mathrm{av}_{\min\mathrm{G}}}^{i,u}\right) \\ -\rho_1 W_1^{i,u} Q_{1G}^{i,u} + \rho_2 W_2^{i,u}\left(Q_{2\mathrm{G}}^{i,u} - Q_{\mathrm{baseG}}^{i,u}\right) \\ +\rho_2 W_3^{i,u}\left(Q_{3\mathrm{G}}^{i,u} - Q_{\mathrm{baseG}}^{i,u}\right) + \frac{1}{2}\rho_3\, W_3^{i,u}\left(\left(Q_{3\mathrm{G}}^{i,u}\right)^2 - \left(Q_{\mathrm{AG}}^{i,u}\right)^2\right) \end{array}\right) \tag{9}$$

The output reactive power is divided into three parts of Q_1–Q_3 according to (9) which indicate amount of reactive power offered at $(Q_{\min},\ 0)$, $(Q_{\mathrm{base}},\ Q_A)$ and $(Q_A,\ Q_B)$. Variable $W_0^{i,u}$ would have value of 1 if the generator is selected to produce in reactive power (absorb or reactive generation) indicating that it would receive availability cost [2].

3.3 Clearing at separate active and reactive powers

Cost functions (8) and (9) need to be minimised in order to optimise load flow and determine active and reactive power production costs. The following constraints are considered for optimal load flow.

3.3.1 Load flow constraints

$$\sum_{u=1}^{NU_i} P_{\mathrm{G}}^{i,u} - P_{\mathrm{D}i} = \sum_{j=1}^{NB}\left|V_i\right|\left|V_j\right|\left|Y_{ij}\right|\cos\left(\delta_i - \delta_j - \theta_{ij}\right) \tag{10}$$

$$\sum_{u=1}^{\mathrm{NU}_i} Q_{\mathrm{G}}^{i,u} - Q_{\mathrm{D}i} = \sum_{j=1}^{\mathrm{NB}}\left|V_i\right|\left|V_j\right|\left|Y_{ij}\right|\sin\left(\delta_i - \delta_j - \theta_{ij}\right) \tag{11}$$

3.3.2 Constraints for bus voltage ranges and line current flows:

$$S_{i,j} \le S_{i,j}^{\max} \tag{12}$$

$$V_j^{\min} \le V_j \le V_j^{\max}, \quad \forall j \in \text{loadedbuses} \tag{13}$$

3.3.3 Constraints for active and reactive power generations by units:

$$P_{\mathrm{G}}^{\min} \le P_{\mathrm{G}}^{i,u} \le P_{\mathrm{G}}^{\max} \tag{14}$$

$$W_0^{i,u},\ W_1^{i,u},\ W_2^{i,u},\ W_3^{i,u} \in \{0,\ 1\} \tag{15}$$

$$Q_{\mathrm{G}}^{i,u} = Q_{1\mathrm{G}}^{i,u} + Q_{2\mathrm{G}}^{i,u} + Q_{3\mathrm{G}}^{i,u} \tag{16}$$

$$W_1^{i,u} Q_{\min\mathrm{G}}^{i,u} \le Q_{1\mathrm{G}}^{i,u} \le 0 \tag{17}$$

$$W_2^{i,u} Q_{\mathrm{baseG}}^{i,u} \le Q_{2\mathrm{G}}^{i,u} \le W_2^{i,u} Q_{\mathrm{AG}}^{i,u} \tag{18}$$

$$W_3^{i,u} Q_{\mathrm{AG}}^{i,u} \le Q_{3\mathrm{G}}^{i,u} \le W_3^{i,u} Q_{\mathrm{BG}}^{i,u} \tag{19}$$

$$W_1^{i,u} + W_2^{i,u} + W_3^{i,u} \le 1 \tag{20}$$

$$W_0^{i,u} = W_1^{i,u} + W_2^{i,u} + W_3^{i,u} \tag{21}$$

Constraint (14) shows that power produced by a unit should not go beyond min–max range designated for it. Constraints (16)–(19) show the offered reactive power amount for each unit at different zones. Constraint (20) states that between variables $W_1^{i,u}$, $W_2^{i,u}$, and $W_3^{i,u}$

only one can have value of 1 at a time; therefore, a unit can only produce reactive power at one zone at a time. Constraint (21) ensures that a unit will receive the availability cost payment if it operates at one of reactive power absorption or production or opportunity zones. Constraints pertaining to synchronous generator capability curve are similar to (5)–(7) again [2].

3.3.4 Constraints of MCP determination for active and reactive power markets: The highest price proposed by generating units would be selected as equalised MCP. The following constraints ensure that market price is actually the highest proposed price which is accepted amongst a set of proposed prices

$$W_{\mathrm{P}}^{i,u} P_{\mathrm{G}}^{i,u} \leq \rho_{\mathrm{P(MCP)}} \tag{22}$$

$$W_0^{i,u} a_0^{i,u} \leq \rho_0 \tag{23}$$

$$W_1^{i,u} m_1^{i,u} \leq \rho_1 \tag{24}$$

$$\left(W_2^{i,u} + W_3^{i,u}\right) m_2^{i,u} \leq \rho_2 \tag{25}$$

$$W_3^{i,u} m_3^{i,u} \leq \rho_3 \tag{26}$$

Constraint (22) shows the MCP for active power market. Constraints (23)–(26) ensure that MCP for availability, reactive power absorption costs, reactive power production costs, and LOC are at the highest accepted levels, respectively.

4 Holding SARPM

The objective function in simultaneous market includes simultaneous minimisation of production costs both for active and reactive power components. The important point is regarding relations of LOC in simultaneous market which are presented as follows.

4.1 LOC at simultaneous market

Similar to separate active and reactive power markets, a unit will receive LOC if its active power output in simultaneous market is less than its output in separate active market. In the scheme proposed by Zhong and Bhattacharya [2], LOC would be calculated using m_3 coefficient which is determined by reactive power producers themselves; hence, reactive power producers may propose higher price for opportunities and consequently cause price increase. Therefore, the relation pertaining to LOC is different from what was used in separate reactive market. Opportunity costs for generators in [12] is calculated considering the difference between active power generation in simultaneous market and separate market of active power, and also based on active power clearing price difference between those two markets. Therefore, should a generator lose the opportunity of selling active power in simultaneous market just because of selling reactive power in comparison with separate market, all lost amounts would be paid to it accordingly. Hence, the LOC function for a unit includes the difference of profits it makes for reactive power generation in separate and simultaneous markets. However, it should be added that a unit only receives LOC if it generates more reactive power in simultaneous market and enters opportunity zone ($Q_{(\mathrm{sim})}^{i,u} > Q_{A(\mathrm{sim})}^{i,u}$) in that market. In other words, generated amount of active power by the unit should be a consequence of generating more reactive power in simultaneous market to make the unit eligible for receiving LOC.

Modified LOC structure would be

$$\mathrm{LOC}^{i,u} = \begin{cases} \Phi_{\mathrm{sep}}^{i,u} - \Phi_{\mathrm{sim}}^{i,u}, & \text{if } \Phi_{\mathrm{sim}}^{i,u} \langle \Phi_{\mathrm{sep}}^{i,u},\ Q_{(\mathrm{sim})}^{i,u} \rangle Q_{A(\mathrm{sim})}^{i,u} \\ 0, & \text{else} \end{cases} \tag{27}$$

$\Phi_{\mathrm{sep}}^{i,u}$ and $\Phi_{\mathrm{sim}}^{i,u}$ in (27) indicate profits for unit u connected to node i in separate and SARPM markets, respectively, which are calculated as

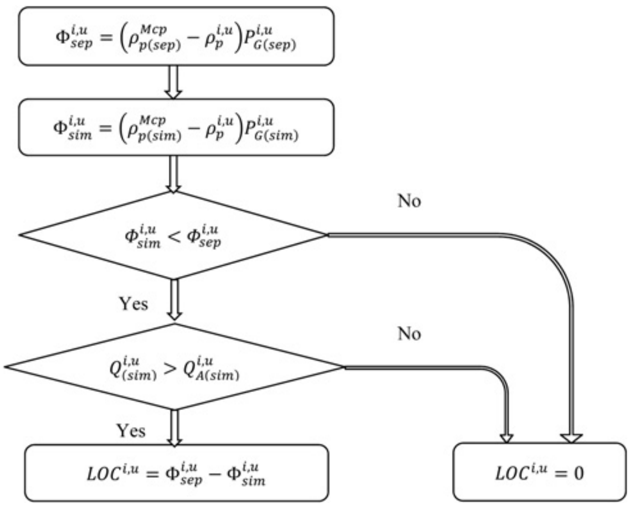

Fig. 2 *Block diagram for LOC payment process*

$$\Phi_{\mathrm{sep}}^{i,u} = \left(\rho_{\mathrm{p(sep)}}^{\mathrm{MCP}} - \rho_{\mathrm{p}}^{i,u}\right) P_{\mathrm{G(sep)}}^{i,u} \tag{28}$$

$$\Phi_{\mathrm{sim}}^{i,u} = \left(\rho_{\mathrm{p(sim)}}^{\mathrm{MCP}} - \rho_{\mathrm{p}}^{i,u}\right) P_{\mathrm{G(sim)}}^{i,u} \tag{29}$$

The LOC payment processis shown in Fig. 2.

4.2 SARPM model

The object function in SARPM includes simultaneous minimisation of active power generation costs, reactive power generation costs, and LOCs. Hence, objective function in SARPM is defined in this study as

$$\text{minimise} \left(\begin{array}{c} \sum_{i=1}^{\mathrm{NB}} \sum_{u=1}^{\mathrm{NU}_i} \left(W_{\mathrm{p}}^{i,u} \rho_{\mathrm{P(MCP)}} P_{\mathrm{G}}^{i,u} \right) \\ + \sum_{i=1}^{\mathrm{NB}} \sum_{u=1}^{\mathrm{NU}_i} \left(\begin{array}{c} \rho_0 W_0^{i,u} \left(Q_{\mathrm{av_{maxG}}}^{i,u} - Q_{\mathrm{av_{minG}}}^{i,u} \right) \\ -\rho_1 W_1^{i,u} Q_{1\mathrm{G}}^{i,u} + \rho_2 W_2^{i,u} \left(Q_{2\mathrm{G}}^{i,u} - Q_{\mathrm{baseG}}^{i,u} \right) \end{array} \right) \\ + \sum_{i=1}^{\mathrm{NB}} \sum_{u=1}^{E_i} \mathrm{LOC}^{i,u} \end{array} \right) \tag{30}$$

Proposed prices for reactive power production by generators in zone three are equal to those in zone two, since LOCs are calculated separately in this type of market. Thus, payments made to generators working in zone three would be equal to payments for working in zone two. Therefore, output reactive power is divided into two parts: Q_1 for absorption and Q_2 for production of reactive power.

4.3 Market clearing at SARPM

Following constraints need to be satisfied when clearing the SARPM market in (30).

4.3.1 Load flow and voltage–current range constraints: Load flow and voltage/current boundary constraints are similar to (10)–(13) above.

4.3.2 Active and reactive power production constraints: The constraint for active power production range is similar to (14). Moreover, constraints regarding reactive power production are similar to (15)–(21), but the power produced by each generator is divided into two parts (Q_1 for absorption and Q_2 for reactive generation) here. Therefore, those constraints are modified as

$$W_0^{i,u},\ W_1^{i,u},\ W_2^{i,u} \in \{0,\ 1\} \tag{31}$$

$$Q_G^{i,u} = Q_{1G}^{i,u} + Q_{2G}^{i,u} \tag{32}$$

$$W_1^{i,u} Q_{\mathrm{minG}}^{i,u} \le Q_{1G}^{i,u} \le 0 \tag{33}$$

$$W_2^{i,u} Q_{\mathrm{baseG}}^{i,u} \le Q_{2G}^{i,u} \le W_2^{i,u} Q_{\mathrm{maxG}}^{i,u} \tag{34}$$

$$W_1^{i,u} + W_2^{i,u} \le 1 \tag{35}$$

$$W_0^{i,u} = W_1^{i,u} + W_2^{i,u} \tag{36}$$

Moreover, relations pertaining to generator capability curves would be similar to (5)–(7).

4.3.3 Constraints of MCP determination: The constraint pertaining to active power market is similar to (22). Those for reactive power market are

$$W_0^{i,u} a_0^{i,u} \le \rho_0 \tag{37}$$

$$W_1^{i,u} m_1^{i,u} \le \rho_1 \tag{38}$$

$$W_2^{i,u} m_2^{i,u} \le \rho_2 \tag{39}$$

5 Holding regional SARPM

For a regional SARPM market, a vast network is to be divided into a number of separate voltage control regions and then SARPM models should be presented considering local characteristics of reactive power in each region.

Segmentation through omitting smaller non-diagonal elements in normalised complete Q–V and Jacobean matrices has been reported in [22, 23]. However, it is difficult to choose an appropriate alpha threshold for omitting non-diagonal elements in that method. Another method of segmentation which is used by the present study is to use electrical distance concept [24]. This method calculates the electrical distance between all the nodes in the system using sensitivity matrix $[\partial V/\partial Q]$, and then determines the segments using a hierarchical clustering algorithm [13]. The vast network would be then divided into a number of separate regions based on voltage control regions; and each power producing unit will submit its proposition within the voltage control region. Finally, different MCPs are calculated for every region.

With this all said, the payment function for regional simultaneous energy and reactive power market for a network with m voltage control region is proposed as follows

$$\min\left\{\sum_{i=1}^{\mathrm{NB}}\sum_{u=1}^{\mathrm{NU}_i}\left(W_P^{i,u}\rho_{P(\mathrm{MCP})}P_G^{i,u}\right) + \sum_{R=1}^{m}\mathrm{RPF}_{\mathrm{zone}R} + \sum_{i=1}^{\mathrm{NB}}\sum_{u=1}^{\mathrm{NU}_i}\mathrm{LOC}^{i,u}\right\} \tag{40}$$

$$\mathrm{RPF}_{\mathrm{zone}R} = \sum_{\substack{i=1\\ i\in\mathrm{zone}\ r}}^{\mathrm{NB}}\sum_{u=1}^{\mathrm{NU}_i}\begin{pmatrix}\rho_{0,r}W_0^{i,u}\left(Q_{\mathrm{av}_{\mathrm{maxG}}}^{i,u} - Q_{\mathrm{av}_{\mathrm{minG}}}^{i,u}\right)\\ -\rho_{1,r}W_1^{i,u}Q_{1G}^{i,u} + \rho_{2,r}W_2^{i,u}\left(Q_{2G}^{i,u} - Q_{\mathrm{baseG}}^{i,u}\right)\end{pmatrix} \tag{41}$$

First term in relation (40) is pertaining to energy market cost. Energy market is not regional and is held over all the system as a whole. Second term in (40) is associated with reactive power costs which is the sum of reactive power costs over all voltage control regions and can be calculated as (41). Third term in (40) is associated with LOC which is calculated using (27)–(29). Constraints pertaining to clearing of regional SARPM are proposed and cleared separately for every region.

6 Holding SARPM considering constraints of voltage stability margin and emission allowance

Two constraints pertaining to voltage stability and polluting substances emission limitation are applied to the market as two new constraints. In this direction, the VSM index is used as an instrument to evaluate system voltage stability which is presented through (42) and (43) [12]

$$\mathrm{VSM} = \frac{\mathrm{MVA}^c - \mathrm{MVA}^n}{\mathrm{MVA}^n} \tag{42}$$

$$\mathrm{VSM} \ge \mathrm{VSM}^{\mathrm{desired}} \tag{43}$$

In which, MVA^c and MVA^n are system load at voltage breakpoint and current system load.

Usually, the level of pollution created by each producing unit is presented as a function of power production of that unit [17]. Two primary pollution units are sulphur dioxide (SO_2) and nitrogen oxide (NO_x) which can be modelled using second order or linear diffusion functions [25]. Pollution emission limitation is presented using (44) and (45) for each hour of market operation [17]

$$\sum_{i=1}^{\mathrm{NB}}\sum_{u=1}^{\mathrm{NU}_i} E^{i,u}\left(P_G^{i,u}\right) \le \mathrm{EMC} \tag{44}$$

$$E^{i,u}\left(P_G^{i,u}\right) = \mathrm{ME}^{i,u} + \mu^{i,u}P_G^{i,u} \tag{45}$$

EMC and $\mathrm{ME}^{i,u}$ are the allowed limit of total pollution emission and minimum pollution created by each unit, respectively. $E^{i,u}(P_G^{i,u})$ is the total pollution created by the unit and $\mu^{i,u}$ is the pollution coefficient for power production which is calculated for SO_2 and NO_x separately.

7 Numerical studies

A 24 node IEEE RTS network is simulated which is shown in Fig. 3 below. Information related to the networkcan be found in [19]. This network consists of 32 producing units and one synchronous condenser connected to node 14. Node 22 is connected to six water units which do not submit propositions to active power; they win this market only if operated at near their nominal capacity. Fig. 3 shows location of each generating unit on network nodes. The mixed integer nonlinear programming model in GAMS software using simple branch and bound algorithm is used to analyse the results.

To compare the results, the separate active and reactive power markets are simulated with regard to reforms in the pricing of reactive power. Then simultaneous market presented in this paper has been implemented and its results are compared with the results of separate active and reactive power markets. The following, the game effect on bidding prices was expressed by the effective units on the cost of provided separate markets and the simultaneous market. Finally, the simultaneous local market model presented in this paper has been evaluated considering VSM constraints and pollution emission limits and also without those considerations.

7.1 Separate active power market

In this part of the simulation, separate active power market model is implemented. Each generator provides its proposed cost as a constant (single step) to ISO in order to participate in this market. Coefficients of cost for each unit are shown in Table 1 along with results of active power market. Minimum and maximum values are shown for each unit as well.

Node voltages are considered to be in range of 0.95–1.06 per unit in this study. Results in Table 1 show that MCP of active power production is \$20.7. This price would be applied to all selected producing units. Two last columns of the table show the

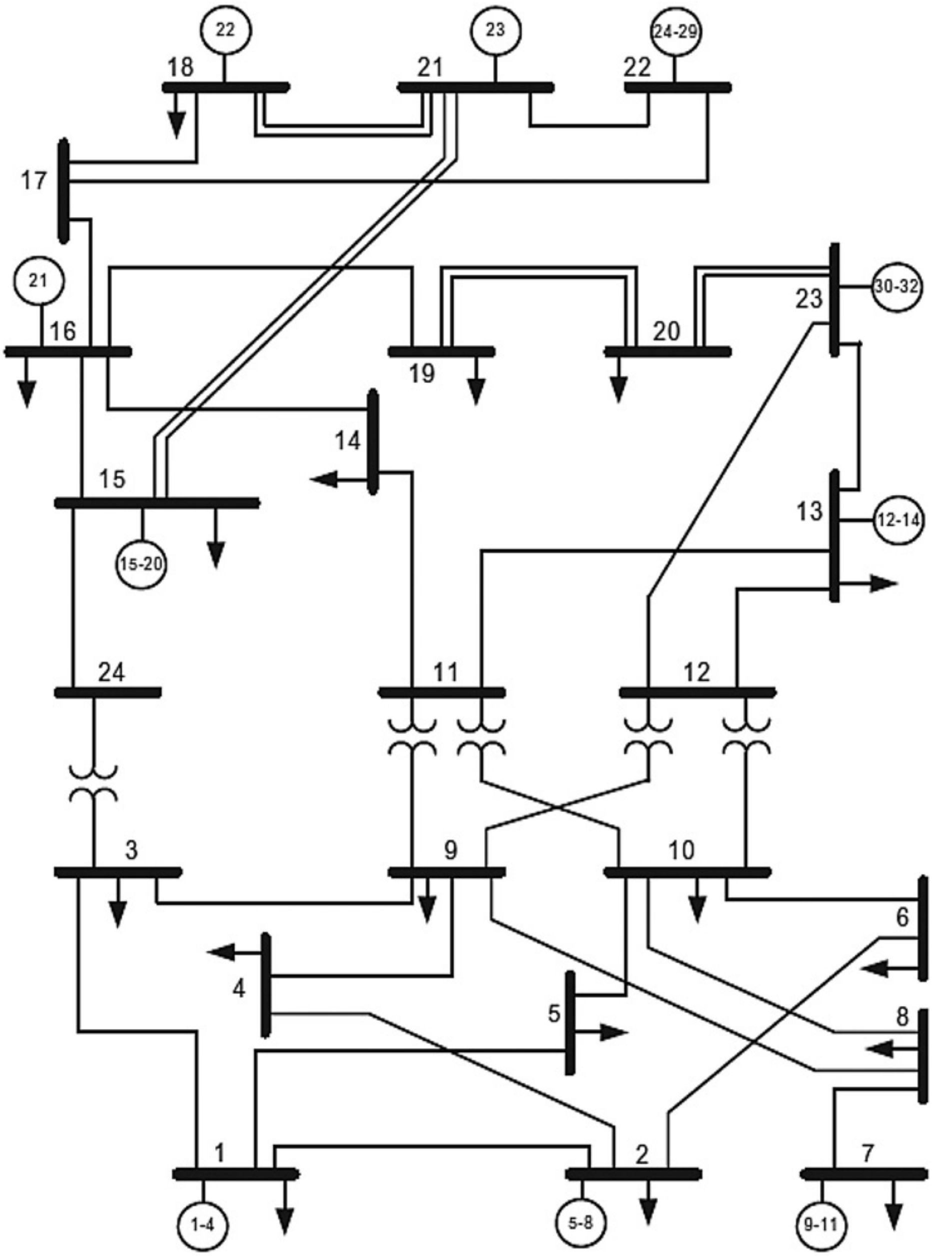

Fig. 3 *24-bus IEEE RTS network*

production volume and the paid amount for all units. As can be observed in the last row, total amount paid to the active power generating units would be $59,576.009.

7.2 Separate reactive power market

In this section, separate reactive power market model is implemented. Each producing unit will submit its proposition in the form of four components: a_0, m_1, m_2, and m_3 to the ISO. Those coefficients are shown in Table 2 along with minimum and maximum values of reactive power for each unit. No LOC is calculated for synchronous condenser connected to node 14 ($m_3 = 0$) and $Q_{\text{base}} = 0.1 \times Q_{\text{max}}$ in this case.

Two last columns of the table indicate reactive power generation by each unit, and payment it has received. Last row shows total amount paid to units and MCPs for separate reactive power market for four components: availability, reactive power absorption, reactive power production, and opportunity costs.

Units 1, 5, 6, 11, 17, 18, and 19 have entered opportunity zone to generate reactive power in this market. ISO would pay $132.280 to those units in total for generating reactive power. Finally, total amount paid to units would be $497.737.

7.3 Simultaneous active and reactive power markets

In this part of this paper, simultaneous market model presented in section (5) has been implemented. Cost coefficients for each unit along with maximum and minimum values of each unit to produce active and reactive powers are the same as Tables 1 and 2. Of course in SARPM model, component associated with opportunity is not included in reactive power generation propositions which units submit to the market ($m_3 = 0$), while loss costs are calculated separately using (27)–(29). Table 3 shows the results obtained from market solution.

Total amount paid to units for producing active and reactive powers in simultaneous market is $59,975.805.

As mentioned above, seven units have entered into opportunity zone in separate reactive power market and received $132.280 in total for working in that zone. However, each unit will generate a level of reactive power which minimises LOC for that unit as well, since LOC is directly integrated into objective function of

Table 1 Prices proposed by synchronous generators for separate active power market, along with results obtained for the market

Bus number	Unit number	Active power market input			Active power market output	
		ρ_P, \$/MW-h	Min, MW	Max, MW	Generation, MW	Payments, \$
1	1	55	16	20	0	0
	2	55	16	20	0	0
	3	13	15	76	76	1573.2
	4	13	15	76	76	1573.2
2	5	55	16	20	0	0
	6	55	16	20	0	0
	7	13	15	76	76	1573.2
	8	13	15	76	76	1573.2
7	9	18.7	25	100	100	2070
	10	18.7	25	100	100	2070
	11	18.7	25	100	90.146	1866.014
13	12	20.7	69	197	197	4077.9
	13	20.7	69	197	197	4077.9
	14	20.7	69	197	197	4077.9
15	15	24.1	2	12	0	0
	16	24.1	2	12	0	0
	17	24.1	2	12	0	0
	18	24.1	2	12	0	0
	19	24.1	2	12	0	0
	20	10	54	155	155	3208.5
16	21	10	54	155	155	3208.5
18	22	5.65	100	400	400	8280
21	23	5.65	100	400	327.413	6777.453
22	24	–	0	50	50	1035
	25	–	0	50	0	0
	26	–	0	50	0	0
	27	–	0	50	0	0
	28	–	0	50	0	0
	29	–	0	50	50	1035
23	30	10	54	155	67.507	1397.402
	31	10	54	155	151.033	3126.378
	32	9.6	140	350	336.969	6975.262
total		active power market MCP = 20.7\$			2878.068	59,576.009

simultaneous market. As it can be observed, units 9, 10, 24, and 29 produce lower active power in comparison with separate active power market; however, those units would not receive payments in compensation for loss since reactive power produced by them in simultaneous market is not high enough to register them to receive payments. In fact, their lower active power production level is

Table 2 Prices proposed by synchronous generators submitted to separate reactive power market along with results obtained from the market

Bus number	Unit number	Reactive power market input						Reactive power market output	
		a_0, \$/MVar-h	m_1, \$/MVar-h	m_2, \$/MVar-h	m_3, \$/(MVar-h)^2	Min, MVar	Max, MVar	Generation, MVar	Payments, \$
1	1	0.096	0.86	0.86	0.56	0	10	7.594	10.332
	2	0.094	0.82	0.82	0.45	0	10	6.667	5.833
	3	0.085	0.79	0.79	0.49	−25	30	0	0
	4	0.083	0.82	0.82	0.30	−25	30	0	0
2	5	0.050	0.54	0.54	0.38	0	10	7.291	8.81
	6	0.042	0.42	0.42	0.45	0	10	7.291	8.81
	7	0.069	0.68	0.68	0.39	−25	30	0	0
	8	0.065	0.62	0.62	0.47	−25	30	0	0
7	9	0.075	0.61	0.61	0.53	0	60	0	0
	10	0.080	0.75	0.75	0.36	0	60	0	0
	11	0.070	0.65	0.65	0.42	0	60	44.517	145.784
13	12	0.068	0.50	0.50	0.41	0	230	0	0
	13	0.070	0.54	0.54	0.49	0	230	0	0
	14	0.075	0.60	0.60	0.50	0	230	76.106	67.751
14	–	0.094	0.81	0.81	0	−50	200	111.470	102.664
15	15	0.065	0.60	0.60	0.40	0	6	0	0
	16	0.050	0.58	0.58	0.35	0	6	0	0
	17	0.060	0.73	0.73	0.38	0	6	6	10.82
	18	0.055	0.61	0.61	0.37	0	6	6	10.82
	19	0.052	0.50	0.50	0.36	0	6	6	10.82
	20	0.051	0.51	0.51	0.57	−50	80	53.333	51.467
16	21	0.050	0.50	0.50	0.50	−50	80	53.333	51.467
18	22	0.090	0.85	0.85	0.85	−50	200	0	0
21	23	0.080	0.75	0.75	0.75	−50	200	0	0
22	24	0.042	0.42	0.42	0.27	−10	16	−8.24	5.957
	25	0.050	0.48	0.48	0.35	−10	16	0	0
	26	0.045	0.42	0.42	0.38	−10	16	−9.3	6.402
	27	0.048	0.44	0.44	0.35	−10	16	0	0
	28	0.049	0.45	0.45	0.43	−10	16	0	0
	29	0.055	0.46	0.46	0.32	−10	16	0	0
23	30	0.090	0.85	0.85	0.58	−50	80	0	0
	31	0.095	0.89	0.89	0.50	−50	80	0	0
	32	0.086	0.80	0.80	0.35	−25	150	0	0
Total		$\rho_0 = 0.096$, $\rho_1 = 0.42$, $\rho_2 = 0.86$, $\rho_3 = 0.56$						368.063	497.737

Table 3 Results of market solution for SARPM

Unit number	Bus number	Active power generation, MW	Reactive power generation, MVar	LOC, $	Total payments, $
1	1	0	6.667	0	6.003
2		0	6.667	0	6.003
3		76	7.44	0	1582.431
4		76	4.546	0	1579.856
5	2	0	2.127	0	1.963
6		0	6.667	0	6.003
7		76	3.229	0	1578.684
8		76	3.229	0	1578.684
9	7	98.535	6	0	2045.442
10		99.535	6.423	0	2066.5
11		100	37.483	0	2103.78
12	13	197	27.296	0	4103.804
13		197	33.306	0	4109.153
14		197	31.991	0	4107.982
–	14	–	75.128	–	73.064
15	15	0	0.6	0	0.576
16		0	0.6	0	0.576
17		0	0.6	0	0.576
18		0	0.6	0	0.576
19		0	0.709	0	0.673
20		155	19.142	0	3230.896
21	16	155	8	0	3220.98
22	18	400	20	0	8304
23	21	400	20	0	8304
24	22	0	1.6	0	2.496
25		0	1.6	0	2.496
26		0	1.6	0	2.496
27		0	1.6	0	2.496
28		0	1.6	0	2.496
29		0	1.6	0	2.496
30	23	70.211	8	0	1465.843
31		155	8	0	3220.98
32		350	15	0	7261.8
total		2878.281	369.049	0	59,975.805
MCP prices			$\rho_{P(MCP)} = 20.7$, $\rho_0 = 0.096$, $\rho_1 = 0$, $\rho_2 = 0.89$		

not a consequence of higher reactive power production, but is caused by new configuration in simultaneous market. In this way, as new proposed configuration of LOCs indicates, none of members has entered opportunity zone, and therefore no LOC is to be paid.

Comparing these results with those in Tables 1 and 2, it can be observed that total paid amount in separate markets of generating active and reactive powers is $60,073.746. This cost is reduced to $59,975.805 for simultaneous market. Total operational cost is lower by $97.941 which suggests that simultaneous market provides a better solution.

7.4 Working with proposed prices in separate and simultaneous markets

The case in which effective producing units increase their proposed prices is simulated here in order to examine the benefit of simultaneous market over separate markets. The results are given in Table 4. In this case, generating unit number 14 increases its proposed price for being available from 0.075 to 0.097 $/MVar-h and its results can be observed in the column named 'change in a_0'. Column named 'change in m_1, m_2' compares the results obtained from cases were the same unit increases its proposal for absorbing and producing reactive power from 0.6 to 0.74 $/MVar-h.

As the last row of the tables shows, operating cost will generally increase in the case unit 14 increases its proposed price. With a_0 increasing, the system operational costs will increase by $138.801 and $53.906 for separate and simultaneous markets, respectively, in comparison with base case. Moreover when m_1 and m_2 increase, the system operational costs would increase by $136.376 and $30.799 in comparison with base case, respectively. Comparing the amounts of increase in operating costs between two types of markets will suggest that the proposed SARPM model in this paper reduces possibility of units' market power.

7.5 Simulating regional energy and reactive power markets

To simulate regional energy and reactive power markets, the 24-bus IEEE RTS network in Fig. 3 was segmented into two separate

Table 4 Amounts paid to units connected to each node for active/reactive power resulted from changes in proposed prices

Bus number	Base case		Change in a_0		Change in m_1, m_2	
	Separate market cost, $	SARPM cost, $	Separate market cost, $	SARPM cost, $	Separate market cost, $	SARPM cost, $
1	3162.565	3174.293	3158.066	3175.908	3159.688	3175.692
2	3164.02	3165.334	3158.066	3165.756	3158.066	3165.622
7	6151.798	6215.722	6328.926	6215.276	6326.634	6215.103
13	12,301.451	12,320.939	12,312.724	12,320.057	12,313.887	12,319.46
14	102.664	73.064	85.268	83.595	82.072	81.369
15	3292.427	3233.873	3276.339	3226.353	3276.616	3223.86
16	3259.967	3220.98	3259.967	3221.11	3259.967	3220.98
18	8280	8304	8280	8304.25	8280	8304
21	6777.453	8304	6777.453	5655.951	6777.453	6675.54
22	2082.359	14.976	2076.696	4155.132	2076.696	3119.976
23	11,499.042	11,948.623	11,499.042	10,506.324	11,499.042	10,505.002
total	60,073.746	59,975.805	60,212.547	60,029.711	60,210.122	60,006.604

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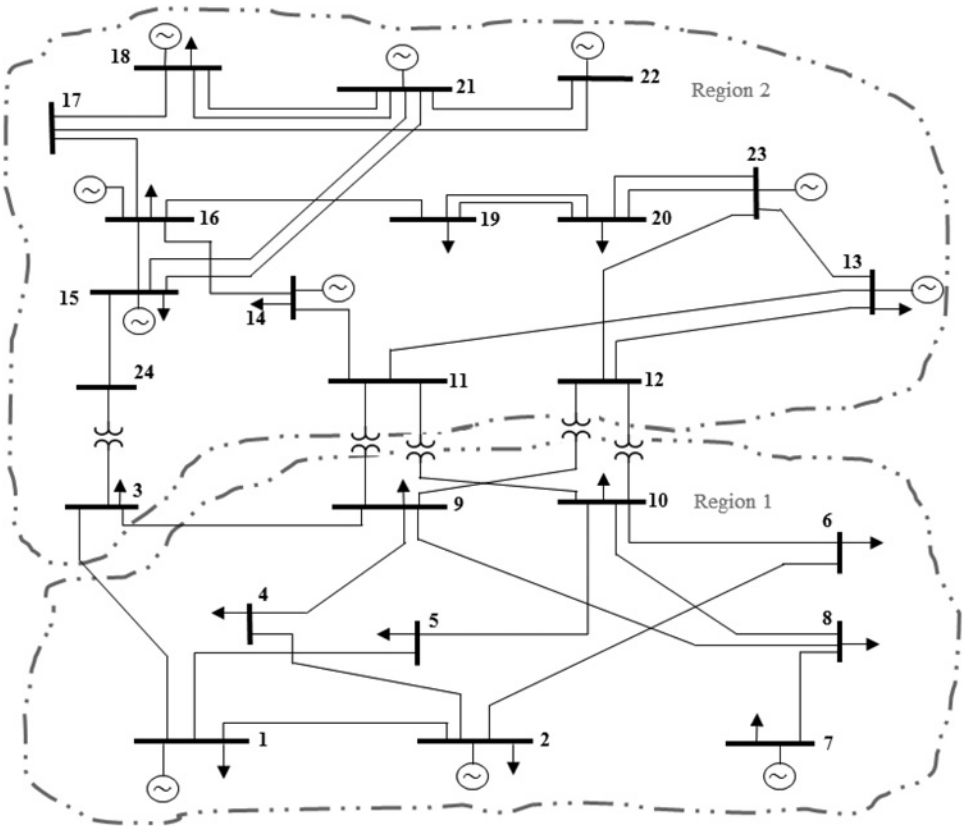

Fig. 4 *24-bus IEEE RTS with two voltage control regions*

Table 5 Results of regional SARPM

Zone	Bus number	Unit number	Active power generation, MW	Reactive power generation, MVar	Region MCP	LOC ($)	Payments ($)
zone #1	1	1	0	3.168	$\rho_0 = 0.096$, $\rho_1 = 0$,	0	2.825
		2	0	1	$\rho_2 = 0.86$	0	0.96
		3	76	13.041		0	1587.115
		4	76	8.11		0	1582.874
	2	5	0	6.666		0	5.833
		6	0	2.586		0	2.314
		7	76	3		0	1578.48
		8	76	3		0	1578.48
	7	9	100	37.891		0	2103.186
		10	98.563	6		0	2046.022
		11	99.506	6.015		0	2065.577
zone #2	13	12	197	43.614	$\rho_0 = 0.095$, $\rho_1 = 0$,	0	4118.096
		13	197	25.238	$\rho_2 = 0.89$	0	4101.741
		14	197	23.742		0	4100.41
	14	–	–	75.128		–	72.814
	15	15	0	4		0	3.596
		16	0	3.118		0	2.811
		17	0	0.6		0	0.57
		18	0	0.6		0	0.57
		19	0	0.6		0	0.57
		20	155	13.333		0	3225.596
	16	21	155	8		0	3220.85
	18	22	400	20		0	8303.75
	21	23	400	20		0	8303.75
	22	24	0	1.6		0	2.47
		25	0	1.6		0	2.47
		26	0	1.6		0	2.47
		27	0	1.6		0	2.47
		28	0	1.6		0	2.47
		29	0	1.6		0	2.47
	23	30	120.603	8		0	2508.841
		31	140.542	8		0	2921.575
		32	314.065	15		0	6517.772
total			2878.279	369.049		0	59,971.79

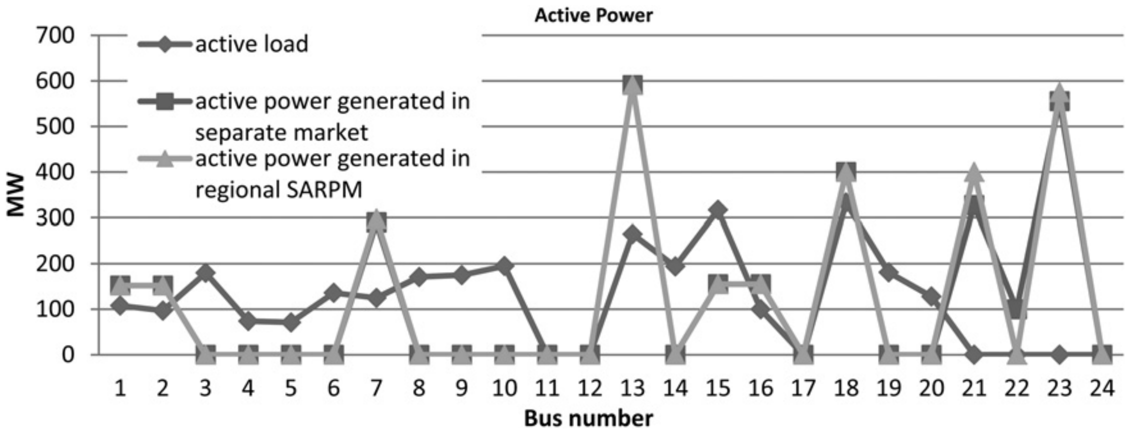

Fig. 5 *Load against production of active power in separate and regional simultaneous markets*

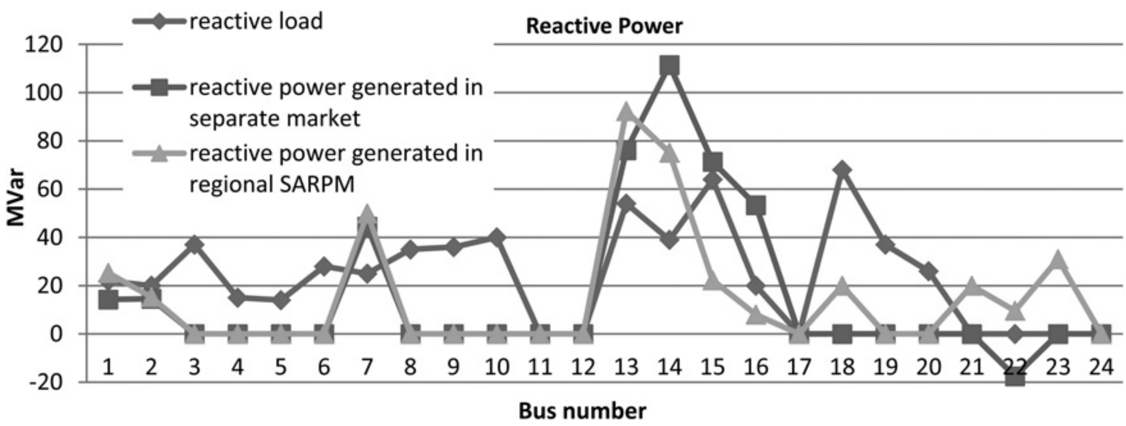

Fig. 6 *Load against production of reactive power in separate and regional simultaneous markets*

regions using electrical distance concept. Results are shown in Fig. 4. The reactive power market is then solved for each region.

The results obtained from regional SARPM are given in Table 5. The amount of generated active and reactive powers for every unit is shown in fourth and fifth columns, respectively, whereas amounts paid to units are shown in the last column.

Lost opportunity is zero for all units in this market as well. Although production volume is decreased for units 10, 24, 29, 31, and 32 in comparison with separate reactive power market, no LOC payment is assigned to those units since reactive power they produced is lower than threshold of opportunity zone.

Comparing the results shown in Table 5 to those obtained from single-region SARPM model, it can be observed that holding two-region SARPM proposed in this study not only considers the local and regional nature of reactive power, but results in lower operating costs for ISO, hence provides a better solution.

Load–production graphs of active and reactive powers associated with separate and regional simultaneous markets are given in Figs. 5 and 6 in order to facilitate the comparison between separate and regional SARPM markets.

Fig. 5 suggests that producing active power in separate and regional simultaneous markets does not create much of an effect. Indeed, although active and reactive markets are held simultaneously in regional SARPM, no negative effect is imposed on diagram of active power production in comparison with the case in which separate active power market held before reactive power market. Fig. 6 shows the superiority of regional SARPM over separate markets in the way reactive power is produced. In the case of separate markets, some buses such as number 14 had produced high amount of reactive power, whereas some others such as bus 22 had to absorb reactive power in order to maintain voltage balance of the system, resulting in higher total operating costs. In regional SARPM, reactive power production graph has followed reactive load, suggesting that no unit had to absorb reactive power in order to maintain voltage balance; this results in less operating costs compared with the case of separate markets.

7.6 Simulating regional energy and reactive power market considering VSM and emission allowance constraints

The simultaneous local market considering voltage stability constraints and pollution emission limitation was evaluated in this section; the obtained results are presented in Table 6. The value of VSM was fixed at 5% for this task. Minimum pollution created by all units was considered here to be zero. Pollution transformation coefficient values were 0.2 and 0.5 for SO_2 and NO_x, respectively [17]. Moreover, pollution emission limitation for NO_x and SO_2 gases were considered to be 12,000 and 5000 pounds per hour, respectively, whereas without considering the pollution emission limitations those values for NO_x and SO_2 gases were 12,920.509 and 5168.204 pounds in simultaneous local market, respectively.

Comparing the results presented in Tables 5 and 6, it can be observed that units' configuration has to be altered in order to satisfy voltage stability and pollution emission limitations; for instance to satisfy the VSM constraint, it is necessary for units 28 and 29 to go online; and this change in units' configuration leads to slight increment in produced reactive power and consequently increases market cost compared with previous optimum state.

Table 6 Results of regional SARPM considering VSM and emission allowance

Zone	Bus number	Unit number	Regional SARPM with VSM			Regional SARPM with emission allowance		
			Active power generation, MW	Reactive power generation, MVar	Total payments, $	Active power generation, MW	Reactive power generation, MVar	Payments, $
zone #1	1	1	0	6.506	5.695	0	6.667	5.833
		2	0	6.667	5.833	0	1	0.96
		3	76	3	1578.48	76	16.724	1590.283
		4	76	10.385	1584.831	76	3	1578.48
	2	5	0	1	0.96	0	1	0.96
		6	0	6.667	5.833	0	1	0.96
		7	76	3	1578.48	76	10.56	1584.982
		8	76	4.984	1580.186	76	3	1578.48
	7	9	98.022	6.723	2035.432	98.678	6	2048.402
		10	100	37.504	2102.853	100	38.217	2103.467
		11	100	6	2075.76	99.344	6.005	2062.185
zone #2	13	12	197	44.642	4119.011	0	68.652	62.481
		13	197	23.23	4099.954	197	23	4099.75
		14	197	25.568	4102.036	197	23	4099.75
	14	–	–	80.293	77.411	–	96.921	92.21
	15	15	0	0.6	0.57	0	2.341	2.119
		16	0	0.6	0.57	0	1.981	1.799
		17	0	0.6	0.57	0	2.341	2.119
		18	0	0.6	0.57	0	2.341	2.119
		19	0	0.6	0.57	0	2.341	2.119
		20	155	8	3220.85	155	15.528	3227.55
	16	21	155	8	3220.85	155	8	3220.85
	18	22	400	20	8303.75	400	20	8303.75
	21	23	318.199	20	6610.474	269.918	20	5611.043
	22	24	0	1.6	2.47	50	1.6	1037.47
		25	0	1.6	2.47	50	1.6	1037.47
		26	0	1.6	2.47	50	1.6	1037.47
		27	0	1.6	2.47	50	1.6	1037.47
		28	50	1.6	1037.47	0	1.6	2.47
		29	50	1.6	1037.47	50	1.6	1037.47
	23	30	149.038	8	3097.443	155	18.539	3230.229
		31	117.795	10.39	2452.84	155	8	3220.85
		32	290.599	19.679	6036.18	350	15	7261.625
total			2878.653	372.837	59,982.812	2885.94	430.758	60,185.18

Regarding the pollution emission limits, unit configuration would alter such that zero emission units (water units located at node 22) will go online, whereas more polluting units such as unit 12 – a steam power plant with fossil fuel – would go offline. Of course this reduction comes with the price of a shift in optimal market operation point; so that reactive and active power productions are increased and consequently market cost would be increased about 213 $ compared with previous conditions.

8 Conclusions

Having enough reactive power is a necessity for a reliable, safe, and robust electrical network. Producing units would be convinced to produce reactive power only if an appropriate pricing strategy is implemented by the system. The price proposition structure for reactive power production is modified through this study in order to create more fair competition in this market. This new structure is represented on a 24-bus IEEE RTS network. On the other hand, reactive power market has been held simultaneously with energy market, since active power and reactive power are related to each other. Moreover, a new structure is presented here to calculate 'LOCs' in reactive and active power markets. The results show that reactive and active power components produced by a number of units enter the opportunity zone and impose higher operating costs to the network. Considering that structure of LOC payment is integrated into objective function of optimisation problem in SARPM, it would be minimised through market solution. Therefore, using SARPM leads to lower amount of LOCs, hence leading to a better solution for the system. Moreover, the SARPM model is presented as a region-based model in order to account for regional nature of reactive power. It was observed that considering local nature of reactive power, the simultaneous market structure proposed in this study has led to a decrease of operating costs while improving reactive power production practices.

Afterwards, the voltage stability constraints and pollution emission limits were applied to the simultaneous local market model; it was observed that adding those constraints leads to increasing system operation costs.

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