VOL. 16, NO. 19, OCTOBER 2021 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

GA BASED REACTIVE POWER PROCUREMENT COST OPTIMIZATION OF DEREGULATED ELECTRICITY MARKET

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ABSTRACT

RPP is one of the most essential ancillary service. In VIU, generation, transmission and distribution activities are taken care by the single monopoly utility and the ancillary services like reactive power provision and voltage control are considered as service so they were included in the energy price. In DEM, Reactive Power support is treated as ancillary service so the supply of reactive power to sustain voltage security becomes a critical problem in competitive environment. The reactive power providers must be remunerated for their reactive electricity facilities. In order to ensure the efficient and safe functioning of the whole power grid, the correct reactive power procurement process and proper handling of RP support must be taken care of by ISO. The emphasis of this paper is optimal Reactive Power Provision by minimizing Total Market Payment for the procurement of reactive capacity. The GA is used to solve Reactive Power Procurement Problem and implemented on IEEE 24 bus system.

Keywords: reactive power (RP), reactive power provision (RPP), vertically integrated utilities (VIU), total market payment (TMP), open access system (OAS), reactive power cost (RPC).

INTRODUCTION

Energy sectors have been run under a strong regulation historically up to nineties, where all the tasks from generation to final distribution to final consumer and electricity markets were performed by VIU. Increase of generation and transmission facilities does not meet the continuously varying electrical energy demands due to many factors such as ROW problems, bulk capital investment for transmission of energy [1]. In a VIU system, the generation, transmission and distribution of energy were looked by single utility organisation and thus ancillary service charges were included in the energy price [2].While, Electricity reforms has increased the competition in the generating segment by separately juxtaposing generation and transmission activities. Figure-1 shows different ancillary services performed by different stack holders in the deregulated power system.

This paper is organized in different sections to incorporate various researches in the area of RP management. Section 2 describes importance of RPP methods. Section 3 represents RPP method and section 4 discuss result and analysis.

Reactive Power Procurement

An adequate reactive power support with proper availability of VAr sources at appropriate location is upmost importan to have the terminal voltages within tolerable limits in deregulated system. Localised nature of Reactive power and abundant need of RP for safe, efficient and consistent operation of the power system makes RP support service very critical issue in deregulated system[3]. To allocate RPC various methods based on empirical formulas are suggested by different researcher's likes triangular relationship between real power and RP or cost based on generator capability curve [4].

Xiea, Songa, DepingZhangb, Nakanishib, Nakazawa (2004) applied the PDIP algorithm on IEEE standard 30 bus system and checked how the Lagrangian multipliers affects on ancillary services in spot pricing [4]. They have approximated reactive power coefficients as one tenth of active power constant for the second-order polynomial for the reactive power cost but this approximation is not valid for all range of reactive power as investment , operation cost, availability of generator and lost opportunity costs are not included in it. Based on the bids submitted by reactive power providers reactive power procurement cost and schedule are decided. For the pool model-based power market Zhao, Irving and Song (2005) has suggested novel pricing approach for reactive power [5]. Based on economic pricing strategies and triangular relationship, the reactive power production costs are obtained for different providers.[5].

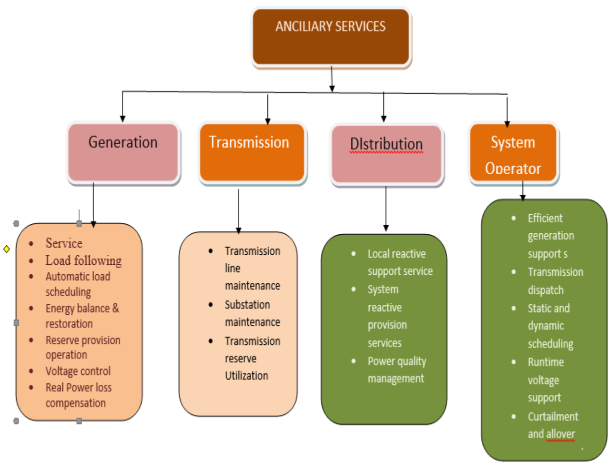

Figure-1. Various ancillary services.

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A fair, accurate and realistic cost calculation method for the reactive power procurement is suggested by Hasanpour, Ghazi, and Javidi proposed [6]. Moghaddam, Raoofat, Fam (2006) has proposed new perception based on the Incremental Transmission Loss Allocation Technique (ITLA) in which the loss of particular contract and specific unit in a multilateral OAS is calculated after considering the reactive power procurement [7]. Bhattacharya, Samahy and Canizares proposed the three-step method to maximize the social welfare and consider the estimation of marginal welfare and depends on acceptable Lagrange multipliers relating to the power relation of the generator[8]. The RP occupies considerable part of transmission line capacity and reduces active power flow.Hence, It is important to calculate Reactive Power Transmission Cost (RPTC) along with generation cost. Dariush Shirmoharnnadi, Paul R. Gribik, Malinowski, O'Donnell describe MW-Mile method for the transmission pricing method [9].

The terminal voltages should be kept within tolerable limits by providing an adequate reactive power support [10] for satisfactory operation of the electrical power eqapparatus. For safe and reliable operation of power system, RP is very essential. In VIU, Reactive Power Provision is considered as operational service of system and cost of RP is calculated approximately and integrated in energy tariff [11]. The penalty factor calculated from power factor is used to compensate the reactive power cost in many market. Some market consider only synchronous generator as reactive power provider and eligible for remuneration [12].

In modern power system, voltage stability is major concern as power system mostly run under stressed conditions due to inadequate expansion of generation and transmission facilities against continuously increasing demand.To enhance power transfer capability and controllability of transmission line, Flexible A.C. Transmission System (FACTS) are used which provide reactive shunt compensation [13]. Mala de has formulated OPF problems and solved using Artificial Bee Colony (ABC) algorithm and analyzed RPP problems for both normal and contingency condition to find out its impact on voltage stability [14].

Saied Salamat Sharif used various classical and several evolutionary computing based optimization techniques to solve ORPD problem [15]. Various researcher used different objective functions like Cost minimization, voltage stability improvement, losses minimization, and terminal voltage deviation minimization to solve reactive power planning and dispatch problem and tested on several standard IEEE bus system. Chao-Rong Chen, Hang-Sheng Lee and Wenta Tsai has discussed reactive power planning problem and used Genetic Algorithm as optimization tool [16] while R. Suresh and N. Kumara has focused on reactive power optimization [17]. S. Ahmed and G. Strbac simulated various reactive power markets and analyse reactive power optimization problem for different markets [18]. Aditi Gupta has analysed financial impact of reactive power production by wind farm in deregulated market. Reactive power cost of different generators including distributed sources is calculated using the concept of loss of real power spinning reserve cost [19].

REACTIVE POWER COST CALCULATION

Reactive Power Provider Cost by Various Market Participants

All reactive sources such as synchronous generators, capacitor banks and condensers should be compensated for their services. But country to country, there is a difference in compensation methods of reactive power provision consideration. This work consider all these three sources as RPP and should be paid for their RPP services.

Generator Reactive Power Cost

Generators supplies reactive power needs of system and its cost contain main two parts: fixed cost and variable cost. The operating cost is variable cost and it includes while the opportunity cost is variable cost for reduced active power generation to fed increased reactive power requirement to maintain terminal voltages at load buses. An approximate reactive pricing techniques either uses the opportunity cost or only the operation and investment costs.Conventionally, equation (1) shows active power cost and equation (2) gives approximate generator reactive power cost obtained from active power cost coefficient [4].

$$Cost(P) = a_p\, P^2 + b_p\, P + c_p \tag{1}$$

$$Cost(Q) = 0.05\, b_p Q^2 \tag{2}$$

An equation (1) gives accurate active power cost and equation (2) gives approximate RPC of generator which considers the operating cost of RP from generator only.In conventional method only operational cost is consider which give inaccurate approximate reactive power cost. To overcome this limitations, Song, Irving and Zhao used power triangle.They have replaced active power by reactive power using triangular relationship and suggested equation (3) for RPC calculation.

$$Cost(Q) = a"\mathrm{Q}^2 + \mathrm{b}"\, Q + c" \tag{3}$$

where,

$$a" = a_p sin^2\theta \tag{4}$$

$$b" = b_p\, sin\theta \tag{5}$$

$$c" = c_p \tag{6}$$

These mathematical formulation of RPC also gives wrong fixed cost as generator cost depends on active power generation. In some other work, Xie has used second-order polynomial and has estimated a_q, b_q and c_q constants as one-tenth of active power cost constants but it

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is effective for a exclusive range of RP production. In this work reactive cost allocation cost is calculated which consider investment, operation and opportunity costs also. In generator, apparent power (s) is given by equation (7).

$$S^2 = P^2 + Q^2 \tag{7}$$

If Q=0 than apparent power equals active power and it is maximum value of active power. Hence, at that time S= Pm and active power cost equals C(Pm). To fulfill System's RP needs generator has to produce more reactive power by further reducing its capability to produce active power. Generator i reduces active power production by ΔP as difference between Pm to Pi to generate reactive power Qi.

$$P_i = \sqrt{P_m^2 - Q_i^2} \tag{8}$$

$$\Delta P = P_m - P_i \tag{9}$$

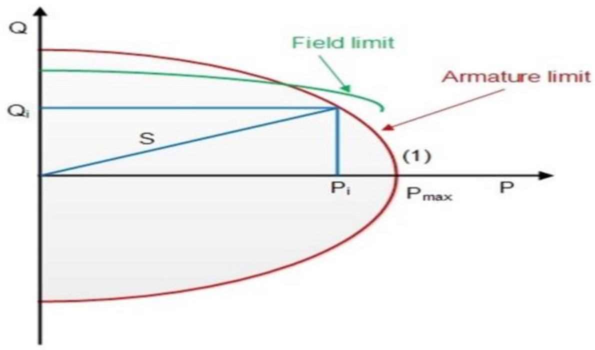

Figure-2. Capability curve of generator.

When reactive power changes from o to Qi, an operating point shifts from point 1 to point 2 in Figure-2.Hence the cost involve due to change in RP generation can be given by equation (10).

$$C(P_m) - C(P_m - \Delta P) = C(Q_i) + \frac{\Delta P}{P_m} C(P_m) \tag{10}$$

$$C(Q_i) = C(P_m) - C(P_m - P_i) - \frac{\Delta P}{P_{max}} C(P_m) \tag{11}$$

$$Cost(Q_i) = \frac{P_m - \Delta P}{P_m} Cost(P_m) - Cost(P_m - P_i) \tag{12}$$

Where,
Cost(Pm) is real power associated with maximum real power Pm
Cost(Pm−P) is total generation Cost when generator produces real power Pi and reactive power Qi
Cost(Pm) − Cost(Pm − P) cost involve with decrease of real power (ΔP) due to increase of RP Qi
$\frac{\Delta P}{P_{max}} C(P_m)$ is cost related to the change of two power points Pm and Pm-P.

An equation(12) can be represented in terms of reactive power as variable by using Eqs.(08) to (12) and RP generation cost can be calculated for different Q. $Cost(Q_{g,i})$ equation can be obtained using Newton–Gregory polynomial, as below:

$$Cost\left(Q_{g,i}\right) = a_{q,i}\, Q_{g,i}^2 + b_{q,i} Q_{g,i} + c_{q,i} \tag{13}$$

Table-1. Transaction matrix.

	G1	G3	G7	G8	G9	G10
D1	0	0	0	0	0	80
D2	30	0	0	0	0	0
D3	0	50	0	0	0	0
D6	0	0	0	20	0	30
D8	0	70	0	0	0	0
D10	0	0	0	20	0	0
D11	0	30	0	0	0	0
D12	0	0	50	0	0	0
D17	0	0	0	0	0	50

But there is a issue for the too many input if we use Newton-Gregory polynomial. The reactive power coefficients are determined by curve fitting technique. This equation is simple and more realistic and it contemplates the operational cost added to the system due to reactive power sustenance and the opportunity cost also. Additionally, investment cost is also precisely amalgamated in it.

Cost of Synchronous Condenser's Reactive Power

An over excited Synchronous motor operating at no load condition generates reactive power. Equation (14) contain investment cost and operating cost of over excited synchronous motor at no load.

$$Cost(Q_{ci}) = (\beta_{ci} + \sigma_{ci}) * Q_{ci} \tag{14}$$

Where, Qci is condenser's RP output, σ is the operational cost of condenser in \$/Mvar-h and βci shows investment cost in \$/Mvar-h

The investment cost βci is expressed by equ. (15).

$$\beta_{ci} = \frac{\text{capital investment cost}}{8760 \times LS \times Ravuse} \ (\$/Mvar*h) \tag{15}$$

Where, LS is lifespan and Ravuse is average usage rate.

Cost of Capacitor's RP

Capacitor is static device hence running cost is calculated by taking $\boldsymbol{\sigma_{capi}} = 0$ in equation (15) and only investment cost is calculated by equation (16).

$$Cost\left(Q_{capi}\right) = \left(\beta_{capi}\right) * Q_{capi}. \tag{16}$$

Transmission Loss Cost

VOL. 16, NO. 19, OCTOBER 2021 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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The cost of RP delivery and transmission energy loss have to be considered in RP market payment. The cost of transmission loss can be described by equation (17)

$$Cost(P_{loss}) = \lambda * P_{loss} \quad (17)$$

Where, Ploss is system transmission loss,
λ is energy price.

Transmission Charge Payment Component

Many researcher has suggested and implemented various tracing methods like Postage stamp methods, Contract Path method, Flat Fee methods, Unused Capacity method, MW-mile Method, Counter flow method, MVA-mile method, Distribution Factor method and. MVAR-Mile method. Here in this paper MVAR-Mile method is used for RPTC calculation as given by equation (18).

$$RPTC = (MVar_i \times C_{qi} \times L_i) \quad (18)$$

Where, $Mvar_i$ is RP flow of i^{th} line,
Cqi is cost per Mvar per unit length,
Li is length of ith line in mile.

The RPTC is calculated based on steps shown in Figure-3 and values are shown in Figure-4. In this paper total 10 transactions are used as shown in the transaction matrix of Table-1 and for the each transaction we calculate the total market payment function.

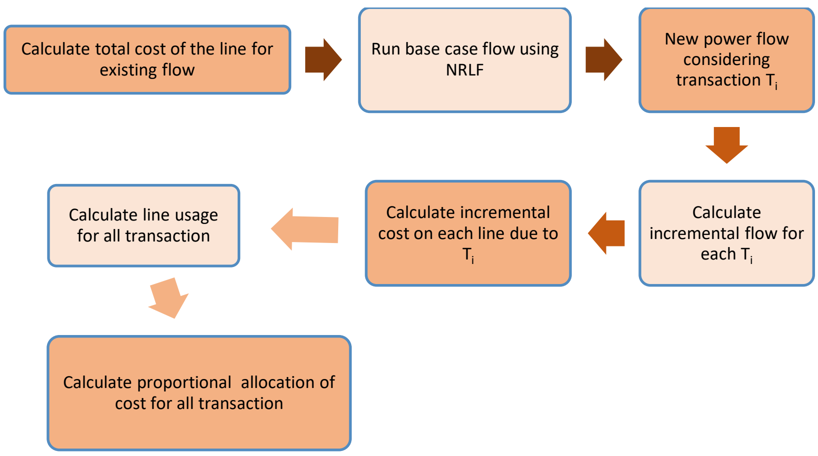

Figure-3. Mvar-mile method for RPTC calculation.

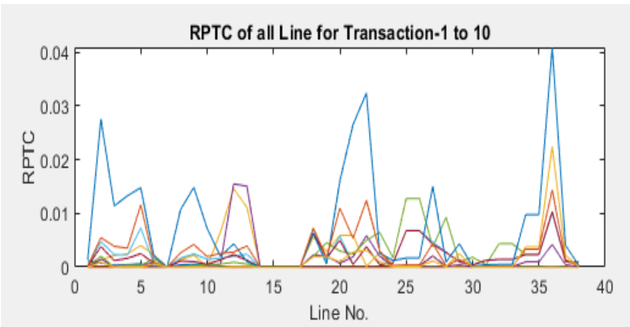

Figure-4. Reactive power transaction charge of each.

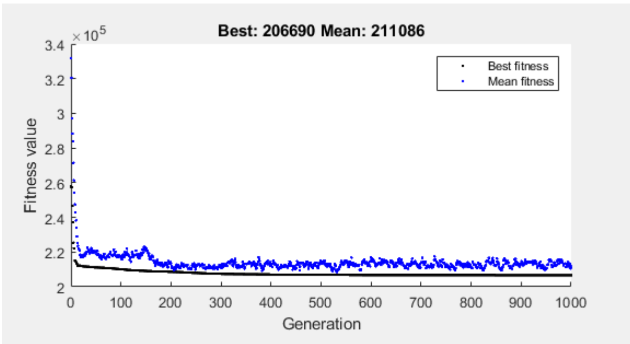

Figure-5. Best and mean value of TMP function.

TOTAL MARKET PAYMENT

Total Market Payment is total amount required to be paid for reactive power support service including RPGC, transmission charges and cost involved in losses.

$$TMP = \left(\sum_k Cost(Q_k) + RPTC + \lambda . P_{loss,i}\right) \forall k \quad (19)$$

Equation (19) shows TMP which consist reactive power generation cost (RPGC), reactive power transaction cost (RPTC) and power loss cost. In this work, the RP generation cost is calculated by using RPC co-efficient. This projected algorithm is applied on RTS IEEE 24-bus system for the calculation of total market payment.

Figure-5 shows optimization curve which gives r best and mean values of total market payment. While Figure-6 shows opimum value for Total market payment for all generation. The best value of Total Market Payment cost is obtained for IEEE 24 bus system and results are obtained.

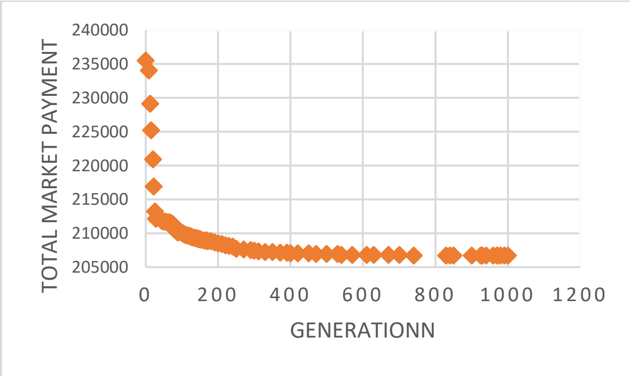

Figure-6. Total market payment optimization curve.

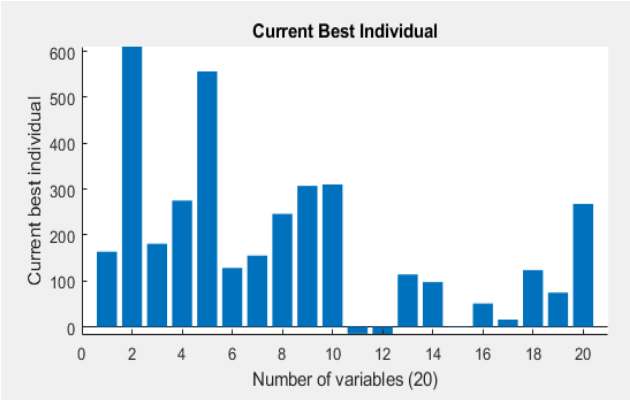

Figure-7. Current best individual for all variables.

Figure-7 represents best value of each variable for IEEE 24 bus system. Figure-8 shows active power generation of all generator at optimum Total market payment and figure 9 shows Reactive Power production at optimum TMP

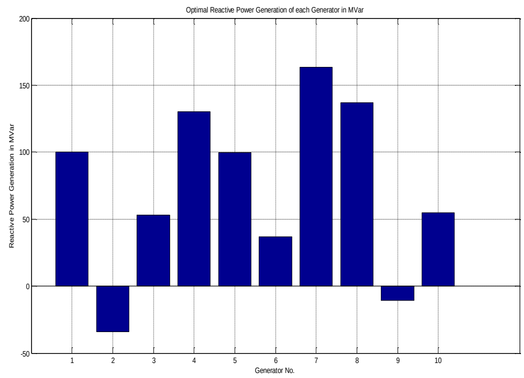

Figure-8. Reactive power generation of all generator.

Table-2. Different cost for individual transactions.

Transaction	Reactive Power Generation cost	RPTC	Real power loss cost
1	4.16E+03	6.02E+02	4.98E+03
2	4.17E+03	1.49E+04	5.05E+03
3	4.16E+03	7.72E+03	5.08E+03
4	4.16E+03	6.26E+03	4.90E+03
5	4.17E+03	1.04E+04	5.19E+03
6	4.17E+03	9.60E+03	5.14E+03
7	4.17E+03	8.31E+03	5.12E+03
8	4.18E+03	3.01E+04	5.49E+03
9	4.17E+03	1.20E+04	5.17E+03
10	4.16E+03	5.29E+03	5.04E+03
Total Cost	4.58E+04	1.05E+05	5.61E+04
TMP	2.07E+05		

Table-2 shows reactive power generation cost, RPTC and real power loss cost and optimum Total market payment.

CONCLUSION

The study of various DEM and the different RP procurement methods are discussed in this paper. The proposed method of the reactive power generation cost calculation from RPC co-efficient is applied on IEEE 24 bus system and solved using GA. An accurate cost of reactive power generation by considering both fixed cost and variable cost. Total market payment function is formulated by considering RPGC, RPTC and cost of loss.

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