Consumer Centric Flexible Reactive Power Pricing using Scalable Technologies

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ABSTRACT

The reactive power is the background power without which the active power cannot be transmitted in the power systems. In the modern power system, the reactive power pricing is very much essential in order to maintain the voltage in the transmission line. The modern power system is the grid that functions with smart innovative technological system that provides flexibility, efficiency and availability for the users. The smart grid uses the Internet of Things technology to identify and provides the requirement of system reactive power for reactive power pricing. The pricing model for reactive power is performed with the aim of loss minimization and thereby meets the consumers in secure manner and provides profit to power producer. The optimal reactive power dispatch problem is solved using Self Balanced Differential Evolution which has multi variable characteristics and the results are compared using Differential Evolution. The computed optimal reactive power of the generator is priced using opportunity cost method. The generator reactive power cost is compared with and without capacitor bank in the 62 Bus Indian utility systems. In this paper, the analytics and opportunities of smart grid for reactive power service are discussed using 62 bus Indian Utility System.

Keywords: Optimal reactive power dispatch, reactive power pricing, smart grid, IoT, cloud.

1. INTRODUCTION

Smart grid is a self-sufficient network that can find quick solutions to the problem in an available system and thereby reduces the human intervention and provides quality electricity to the consumers. Different players like utility providers, system operator and retailers are available in smart grid for effective management of power. The interchange of information and participation of all players in power system operation is important in minimizing the down time and thereby fulfilling the consumers' need [1]. SWOT analysis needs to be done before planning a Smart grid so that grid will be well structured.

According to National Institute of Standards and Technology (NIST), the smart grid is a tedious structure that contains several domains such as power generators, power markets, ancillary service providers, operations manager, power transmission and power distribution [2]. But the grid needs to be modernized due to various factors [3]. First, the production and transmission of electricity has to be done in cost effective manner. Second, the consumers need to be provided with electronic information and automotive equipments to offer necessary information to the consumers about their energy consumption to control their billing cost. Third, in order to integrate the renewable energy sources to the existing system to reduce the greenhouse gas emissions. Fourth, to provide the reliable and secure power service to the consumers. Fifth, to support the increased use of electric vehicles so that, the dependency of vehicle towards fossil fuels is reduced.

According to the Federal Energy Regulatory Commission (FERC) report, the reactive power that is generated from the generators is considered as one of the six supplementary services in the power system [4]. The analysis and importance of reactive power are mentioned in the report by FERC [4]. It has been found that the reactive power is the foremost cause for system shutdown in the United States in the year 2003 [5]. Such reactive power should be maintained in the system for reliable power supply. So, the researchers have started to understand the importance of reactive power both technically and economically. The voltage stability condition is maintained by the optimal reactive power dispatch [6].

The continuous monitoring and prediction of reactive power demand in the system is a difficult task. But it could be made possible using intelligent technologies like Internet of Things (IoT) with the support of cloud computing. Smart grid provides the integration of intelligent equipment with the widespread use of communication technology.

An enormous volume of data such as power demand collection from the consumers, energy generation units, retailers and operators are generated from each and every corner of the smart power grid [7]. The grid system linked with cloud is essential

Manuscript received on February 10, 2018 ; revised on July 25, 2018.
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for fast communication between providers and consumers. The IoT technology in the smart grid provides scalable solutions, managing the time critical events efficiently and provides information security in the system [8-12].

2. REACTIVE POWER SERVICE AND COST

According to FERC, the generator is considered as an important reactive power ancillary service provider. The generation of reactive power by the generator leads to the reduction of real power thereby causing financial loss which could be compensated by the inclusion of reactive power cost in addition to real power cost.This cost of reactive power is called opportunity cost as shown in Eq. 1.

$$C_{Qgi}\left(Q_{gi}\right) = \left|C_{Pgi}\left(\sqrt{P_{Pgi}^2 + Q_{Qgi}^2}\right) - C_{Pgi}\left(P_{Pgi}\right)\right| \times k \quad (1)$$

The real power cost functions are represented as shown in following Eq. 2.

$$C_{Pgi}\left(P_{Pgi}\right) = a + bP_{Pgi} + cP_{Pgi}^2 \quad (2)$$

where cost coefficients a, b and c are in \$/MWhr^2, \$/MWhr and \$/hr. P_{Pgi} is the real power generation of i-th generator. $C_{Pgi}\ (P_{pgi})$ and $C_{Qgi}\ (Q_{gi})$ are the real and reactive power production cost and k is the profit rate. In this paper, k=0.1 [13].

The other important reactive power provider is the capacitor. The investment cost of reactive power service is shown in Eq. 3.

$$C_Q = \frac{Q_{capacity} \times C_{ic}}{lifespan \times usage} = 0.1324 \times Q_{capacity} \quad ;\$/MVArh \quad (3)$$

where C_Q is the reactive power cost of 1 MVAr/ hour, $Q_{capacity}$ is the reactive power output of capacitor in MVAr, C_{ic} is the capacitor initial investment cost in \$/MVAr.

The reactive power that is produced by the above said reactive power providers are utilised by the transmission network and consumers. The cost involved in the reactive power generation is hosted in the cloud by the reactive power providers. Fig. 1 indicates the general architecture of reactive power pricing using IoT and cloud technologies. In real time, the real-power demand is obtained from the consumer side using the intelligent IoT devices and the corresponding reactive power demand is calculated and posted in the cloud. Then, the pricing for reactive power is estimated and made available to the customers through Web and mobile apps with the help of cloud infrastructure. Based on the demand, cost and quality of service, customers can choose the service providers. Once the service provider is chosen with the help of the system operator, the power is then distributed to the power distribution centre. In this paper, we have taken the load data for 62-bus Indian utility system (IUS) from [14] [15].

3. PROBLEM FORMULATION

The power demand varies based on load over day and night. Hence, in the power system, it is necessary to maintain the power balance between production and consumption. The reactive power has to be maintained for varying power demands. The power demands are obtained by using the IoT technology and made available in the cloud infrastructure. The optimal reactive power dispatch and reactive power pricing are the most important factors in the power system. The demand of reactive power is calculated and the pricing is estimated and made available in the cloud storage.

3.1 Minimization of real power loss

The optimal dispatch of the generator reactive power is calculated by minimizing the real power loss [16]. The objective function is represented as Eq. 4,

$$P_{loss} = \sum_{k=1}^{nl} g_k\left(v_a^2 + v_b^2 - 2v_a v_b \cos\left(\delta_a - \delta_b\right)\right) \quad (4)$$

where P_{loss} is the active power loss of TL, nl is the number of TL, g_k is the conductance of line k, v_a and v_b are the bus voltage at a and b, δ_a and δ_b are the angle of voltage at bus a and b respectively.

3.2 Minimization of voltage deviation

The voltage profile at various buses (named as Total Voltage Deviation, TVD) is maintained by minimizing the voltage deviation at load buses from 1.0 p.u [16] as given in the Eq. 5,

$$TVD = \sum_{i=1}^{N_{pq}} \left|v_i - 1\right| \quad (5)$$

The objective function Eq.4 has to be satisfied together with the constraints that include the active and reactive power flow equation, active and reactive power generator and bus voltage operating limits and transmission power limits.

The various controls of the ORPD problem are bus voltage, transformer tap setting and reactive power of shunt compensation. The cost model of reactive power service differs for diverse reactive power sources. Cost based pricing is the recovering cost associated with the production of reactive power. According to FERC, generator is considered as an important reactive power ancillary service provider.

Based on the early discussion in the section 2, the cost of reactive power is compensated during the real

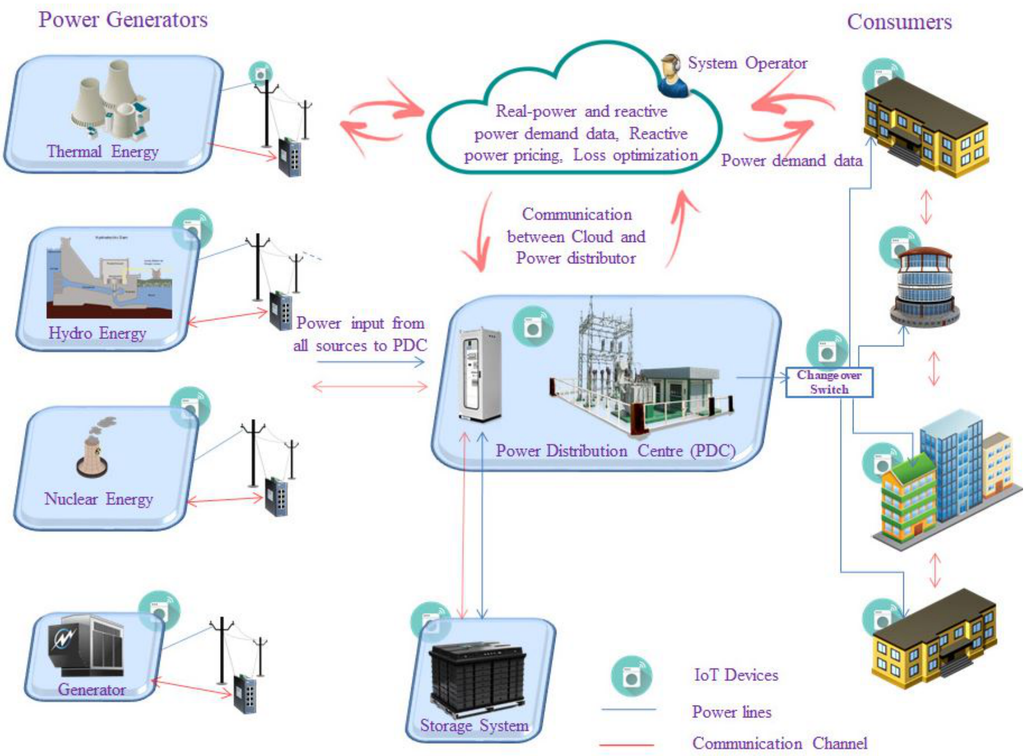

Fig.1: *General architecture of reactive power pricing using IoT and cloud technologies.*

power sale. This cost of reactive power is called opportunity cost as shown in Eq. 1

4. OPTIMIZATION ALGORITHM-SBDE TO ORPD PROBLEM

The optimization problem is solved by various classical techniques. But, these techniques give better solution for continuous and differential equation without constraint. Also, the conventional technique is difficult to solve in a large size system. Various researches have been proved that evolutionary computation technique finds the best solution for complex problem. Here, the Differential Evolution (DE) and improved DE, named Self Balanced Differential Evolution (SBDE) are used to solve the problem.

4.1 Differential Evolution

In 1995, Storn and Price introduced an evolutionary technique called DE [17]. The DE algorithm can be used for ORPD problem. It is a global searching technique and is characterised by its simplicity, robustness and fast convergence. The steps of DE are discussed as follows:

Initialization: The initial step is initializing the population of candidate which is randomly chosen from its operating bounds. The Initialization can be written as Eq. 6,

$$x_{j,i}^{(G)} = x_j^{lowerlimit} + Random \times \left(x_j^{lowerlimit} - x_j^{upperlimit}\right) \quad (6)$$

where $i = 1, 2, ..., Np$ and $j = 1, 2, ..., D$. Np is the population size and D is the problem dimension. The data of power system such as generator data, bus and line data are given as an input. The DE parameters such as population size, number of iterations, problem dimension, scaling factor and crossover ratio are initialised. Every vector of population is initialised and the objective of each solution is computed and stored.

Mutation: The second step is the mutation process. The mutant or donor vector $V_i^{(G)}$ is generated for each target vector x_i. The mutant vector $V_i^{(G)}$ is created such that it demarcates among the various DE strategies. The mutation strategy used here is DE/rand/1. $V_i^{(G)}$ is obtained by combining random vector X_{r1} with the subtraction of two other random vector. The three vectors such as X_{r1}, X_{r2} and X_{r3} which are randomly chosen and obtained from previous step. The vectors X_{r1}, X_{r2} and X_{r3} do not overlap with current target vector x_i. The mutant vector can be found using the following Eq. 7,

$$V_i^{(G)} = x_{R1}^{(G)} + F * \left(x_{R2}^{(G)} - x_{R3}^{(G)}\right) \quad (7)$$

where F is the mutation scaling factor between 0 and 1. Vectors R1, R2, R3 ∈ {1, N_P} and R1 ≠ R2 ≠ R3 ≠ i. where i = 1, 2, ..., N_p.

Crossover: The next step is the crossover which is used to increase the current population diversity. The binomial crossover is used on all the dimension variables with less crossover constant (CR) value. The binomial crossover operation used in this paper can be expressed as Eq. 8,

$$U_i^{(G)} = \begin{cases} V_i^{(G)} if\ random\ j \leq CR \\ X_{j,i}^{(G)} otherwise \end{cases} \tag{8}$$

The DE performs this step to produce the trail vector, $U_i^{(G)}$. This trial vector is produced from the parent and mutant vector in a probabilistic concept. CR is the crossover control parameter between 0 and 1.

Selection: This is the last stage of DE procedure [17]. For minimization problem the vector which is having the lowest fitness value is selected. This existing population vector produces the population in the next iteration as Eq. 9,

$$X_{j,i}^{(G+1)} = \begin{cases} U_i^{(G)} if\ f\left(U_i^{(G)}\right) \leq f\left(X_i^{(G)}\right) \\ X_{j,i}^{(G)} otherwise \end{cases} \tag{9}$$

Once the best solutions are reached, the stopping criteria are checked. Usually the optimization algorithm is stopped whenever the maximum iteration is reached.

DE has few drawbacks such as premature convergence and less exploration of solution space. These drawbacks are overcome using improved Differential Evolution such as Self Balanced Differential Evolution (SBDE).

The mutation process in DE is varied in SBDE due to Cognitive learning factor, C and scaling factor, F. The value of C varies between 0.1 and 1. The small value of C and high value of F explore the search space. Large C value and small F value exploit the solution space [18]. Therefore, appropriate values of C and F balance the diversity of population. Mutation in DE is expressed as in Eq. 10,

$$V_i^{(G)} = C \times x_{R1}^{(G)} + F \times \left(x_{R2}^{(G)} - x_{R3}^{(G)}\right) \qquad i = 1, 2, ..., N_p \tag{10}$$

The implementation of the SBDE to the optimal reactive power dispatch is explained as follows,

4.2 Implementation of SBDE for ORPD problem

1. Initialize the simulation parameters of SBDE such as number of population and control variables, scaling factor, crossover and maximum number of iteration between operating limits.

2. For each individual, fitness function is calculated using Newton Raphson (NR) load flow model.

3. Fix the initial iteration value as $G = 1$.

4. Perform mutation process to produce mutant vector V_i^G.

5. Obtain the crossover operation to introduce trail vector. Find the fitness function and check the constraints.

6. The trial vector and target vector fitness values are compared and best solution has to be selected.

7. If the trail vector provides the best solution than the target vector, update the C value in the next iteration. If the same trail vector is selected for further process, go to step 10, otherwise continue.

8. When there is no change in the individual updating, set $C = 0.1$.

9. Same target vector is selected for next generation.

10. Once the maximum iteration or stopping criteria is reached, go to the next step.

11. The control variables optimal values are obtained. Once the optimal control variables are obtained, then the generator RPD is obtained. The individual contribution of generator reactive power is found and priced.

5. RESULTS AND DISCUSSION

To analyze the performance of DE and SBDE, the proposed algorithms are applied to the ORPD problem of 62 bus IUS. The system has 19 PV buses and 43 PQ buses with 89 transmission lines [14]. The IUS has real power demand of 3028 MW and reactive power demand of 1320 MVAr. The characteristics of generator, loads and transmission lines are taken from [14].

PV bus voltages, transformer tap setting and shunt capacitance are considered as control variables. The number of control variables is 29. The optimization problem is simulated in the system having CPU with a clock speed of 2.2 GHz and 4 GB RAM.

This cloud service is utilized for 62 cities of India as intra-city network. Hence the virtual machines count is equal to 62 and modelled as a data centre. The data collected from different cities are stored in data centre. The demand requirement of consumers are collected and stored in the cloud. The generating units submit the optimal real and reactive power along with the cost for possible cases to meet the consumer requirement and host in the cloud. The consumers select the case and it is explained as follows:
Case 1: Minimization of real power loss as objective function (without capacitor).
Case 2: Minimization of real power loss as objective function (with capacitor).

Case 1: DE and SBDE are used to find the optimal control variables of the real power loss minimization problem. Table 1 shows the simulation values of parameters of DE and SBDE.

The control variables are operating within the limits and it is shown in Table 2.

Table 1: *Values of simulation parameters of optimization algorithm.*

Parameter	DE	SBDE
Number of population	125	
Scaling factor	0.6	0.5
Crossover ratio	0.8	0.4
Number of control variables	29	
Maximum number of iterations	500	

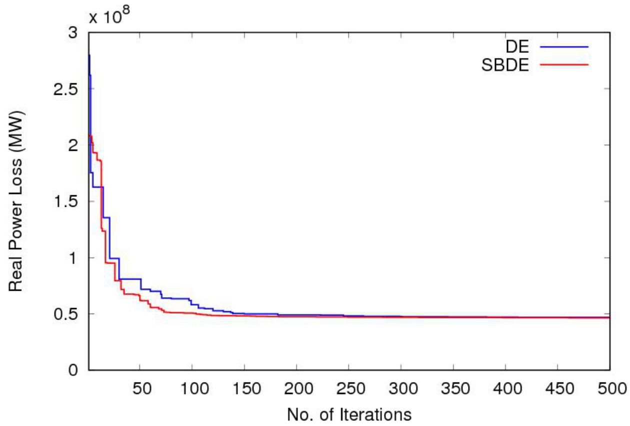

Fig.2: *Convergence characteristics (Case 1).*

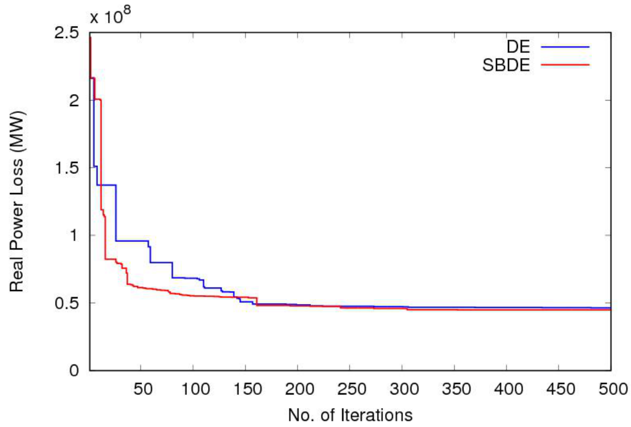

Fig.3: *Convergence characteristics (Case 2).*

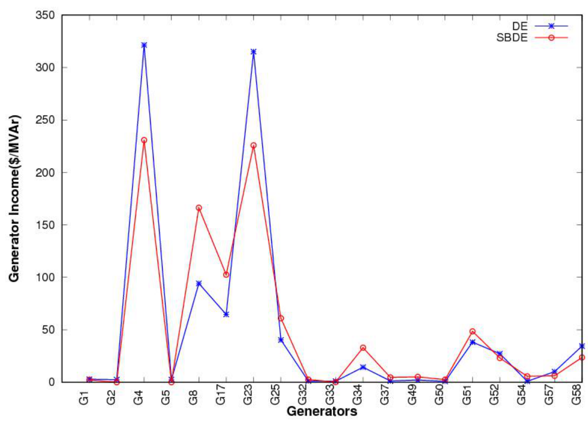

Fig.4: *Reactive power cost for case 1.*

Fig. 2 shows the comparison of convergence characteristics for best solution out of 20 trails. The time taken for best solution is 417.2s using DE and 334.7s using SBDE. Using DE, convergence characteristics of objective function reaches the steady value of 46.9 MW. The optimal control variables are shown in Table 2.

For this control variable, the generator dispatch of real and reactive power is shown in Table 3. Some generators absorb the reactive power, hence operating in under excitation region. The reactive power produced by individual generator is less in order to minimize the transmission loss. The generator reactive power is shown in the Table 3 and this much of reactive power is necessary to maintain the voltage at each bus. Generators G4 and G23 generate more reactive power of 142.01 MVAr and 122.84 MVAr with a cost of 321.44 \$/h and 315.09 \$/h. The cost for remaining generators for reactive power service using DE and SBDE is shown in Fig. 4 for case 1. The total cost of generators reactive power is 975.7 \$/h and 944.4 \$/h.

It is found that the transmission loss is reduced to 46.38 MW using SBDE from 46.9 MW using DE. The convergence time is faster in SBDE with minimum number of iterations. The corresponding cost of generator reactive power using SBDE is 944.4 \$/h which is less than cost obtained using DE.

Case 2: The capacitors are added to find the changes in the reactive power generation and absorption. Since the demand for reactive power at bus 11 and 41 of 62 bus IUS are higher, the capacitors of 30 MVAr are added at these buses. Here the objective function is minimization of loss. It is found that objective function converges to minimum value of 46.4 MW compared to previous case, as shown in Fig. 3. This is due to the impact of capacitor at bus 11 and bus 41 in case 2.

From Table 3, the reactive power absorption is more compared to the previous case. This is due to the capacitor which generates the reactive power before the generator reactive power production. The absorption cost of generator reactive power is more compared to case 1. However, this amount of reactive power absorption should also be priced since it is necessary to maintain the voltage profile at each bus. Higher value of capacitor also leads to more generator reactive power cost. Fig. 5 shows the reactive power cost of each generator using DE and SBDE. The total cost of generator reactive power production using DE is 1025.4 \$/h. The capacitor cost should be added with the generator reactive power cost.Thus, depending upon the load requirement, the optimal value of capacitor should be switched in the system to mini-

Table 2: *Optimal Control variables (Basic DE and SBDE).*

S.No	Variables	DE		SBDE	
		Case 1	Case 2	Case 1	Case 2
1.	$V_{G1(slack)}$	1.00	1.00	1.00	1.00
2.	V_{G2}	1.003	0.999	1.003	1.003
3.	V_{G4}	0.99	1.001	1.0002	1.001
4.	V_{G5}	1.001	1.001	1.003	1.002
5.	V_{G8}	1.003	1.0001	1.004	1.003
6.	V_{G17}	1.092	1.092	1.053	1.036
7.	V_{G23}	1.1	1.1	1.033	1.026
8.	V_{G25}	1.1	1.099	1.035	1.027
9.	V_{G32}	1.095	1.095	1.005	1.029
10.	V_{G33}	1.088	1.091	1.0006	1.026
11.	V_{G34}	1.093	1.094	1.003	1.027
12.	V_{G37}	1.099	1.1	1.010	1.034
13.	V_{G49}	1.045	1.081	1.009	1.068
14.	V_{G50}	1.043	1.072	1.010	1.065
15.	V_{G51}	1.099	1.099	1.037	1.033
16.	V_{G52}	1.1	1.098	1.038	1.031
17.	V_{G54}	1.099	1.0995	1.033	1.034
18.	V_{G57}	1.099	1.1	1.054	1.033
19.	V_{G58}	1.1	1.099	1.053	1.035
20.	T_{1-14}	0.9	0.901	0.974	0.967
21.	T_{14-15}	1.1	1.1	1.025	1.023
22.	T_{4-14}	0.901	0.902	0.977	0.972
23.	T_{13-14}	0.991	0.985	1.027	1.002
24.	T_{12-13}	0.993	0.987	0.982	0.990
25.	T_{14-19}	0.901	0.901	0.9001	0.9002
26.	T_{14-18}	0.9	0.933	0.901	0.9
27.	T_{14-16}	1.023	1.020	0.9823	1.002
28.	T_{48-54}	1.048	1.051	1.013	1.0298
29.	T_{48-50}	1.1	1.0695	1.032	0.999
30.	T_{49-48}	0.908	0.942	0.964	1.002

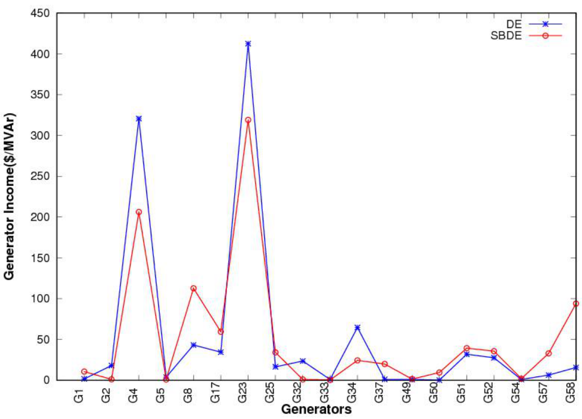

Fig.5: *Reactive power cost for case 2.*

mize the reactive power cost.

The capacitor cost is calculated using Eq. 3 and Eq. 11. If the initial investment cost of capacitor is 11600 \$/MVAr, the average working rate is 2/3 and the lifetime is 15 years.

$$C_Q = \frac{\$11600 \times Q_{capacity}}{15 \times 365 \times 24 \times \frac{2}{3}} = 0.1324 \times Q_{capacity} \quad ; \$/MVArh \tag{11}$$

The reactive power production cost of capacitor is 7.9 \$/h. The reactive power pricing of generator using DE is 1025.4 \$/h. Thus, the total cost of reactive power service is the summation of generator cost and capacitor cost and it is found as 1033.3 \$/h. Table 4 shows the reactive power cost comparison for different cases using DE and SBDE. SBDE shows the minimum loss and minimum reactive power production cost. SBDE gives better performance for case 2. The generator production cost for reactive power is reduced when compared to basic DE and it is found as 1005.4 \$/h. The reactive power production cost of capacitor is added with the generator cost and it yields 1013.3 \$/h. Thus, SBDE is a powerful technique for loss minimization problems.

In case 1, since the real power loss is reduced, the

Table 3: Solution of different cases under base load condition (Using DE and SBDE).

Generators	DE				SBDE			
	Case 1		Case 2		Case 1		Case 2	
	Real power (MW)	Reactive power (MVAr)	Real power (MW)	Reactive power (MVAr)	Real power (MW)	Reactive power (MVAr)	Real power (MW)	Reactive power (MVAr)
G_1	370	13.45	349	10.00	355.4	11.86	354.98	25.37
G_2	100	10	100	26.87	100	1.26	100	6.68
G_4	100	142.01	100	123.76	100	102.57	100	96.27
G_5	20	10	20	13.39	20	-1.35	20	6.16
G_8	120	61.88	120	41.93	120	84.60	120	68.80
G_{17}	300	72.98	300	53.32	300	92.39	300	70.22
G_{23}	100	122.84	100	130.32	100	92.50	100	112.38
G_{25}	500	56.83	500	36.34	500	69.92	500	52.35
G_{32}	200	-7.19	200	-31.76	200	-10.63	200	6.53
G_{33}	30	10	30	10.00	30	4.83	30	6.26
G_{34}	100	38.24	100	74.64	100	52.37	100	44.86
G_{37}	50	11.34	50	10.00	50	20.83	50	45.30
G_{49}	120	-13.23	120	-9.22	120	-20.35	120	-10.75
G_{50}	50	-6.69	50	2.85	50	-11.28	50	-22.22
G_{51}	125	39.46	125	35.80	125	44.28	125	39.83
G_{52}	55	43.81	55	41.79	55	38.11	55	48.14
G_{54}	55	10	55	10.00	55	24.00	55	14.13
G_{57}	150	-30.15	150	-25.48	150	-25.16	150	-38.45
G_{58}	550	51.54	550	34.76	550	42.64	550	85.13
C_{11}	–	–	–	30	–	–	–	30
C_{41}	–	–	–	30	–	–	–	30

Table 4: Reactive power cost comparison of different cases

Optimization algorithm	Case 1 Cost ($/h)		Case 2 Cost ($/h)			
	Real power loss (MW)	Generator reactive power cost ($/h)	Real power loss (MW)	Generator reactive power cost ($/h)	Capacitor cost ($/h)	Total cost ($/h)
DE	46.9	975.7	46.4	1025.4	7.9	1033.3
SBDE	46.38	944.4	44.9	1005.4		1013.3

cost associated with the transmission line is also reduced in the deregulated system. The consumer can check the amount required for reactive power ancillary service and real power transmission charge. The transmission charge for real power is more when the losses are high. So, the real power loss should be reduced and also minimum voltage should be maintained for proper power transmission in economic manner with good voltage regulation. Accordingly, the consumer selects the case which is economical and efficient.

The location of generation varies, thereby the transmission and distribution losses vary which can be reflected in the electricity bill. The reactive power services are provided to consumers by two options. The options are: i) by dynamically generating the reactive power and ii) by obtaining the static reactive power supply from the capacitor. The system operator collects the power requirement details in the cloud with the help of IoT and suggests the feasible cases for reactive power service from which the consumer selects the feasible option based on the demand, quality and cost.

6. CONCLUSION

Modernization of the power system is a long term process and the power providers are working towards achieving the engineering power in the smart grid by minimizing the cost and energy loss. Bringing down the cost associated with reactive power ancillary service in smart grid is an additional task for the power engineers. In this paper, the optimal procurement of reactive power service is carried out using the optimization technique SBDE and the corresponding cost is calculated and it is made available to the consumers. The system operator provides the transparent communication between the suppliers and consumers by facilitating the flexibility to the consumers for choosing the supplier based on the quality and cost.

This work can be implemented in smart grid by automating the real-power and reactive power demand estimation and price calculation using the IoT and Cloud computing technologies. This work can also be extended by analysing the Cloud service costs which includes hardware, software license and maintenance. These costs have to be added as service cost for the consumer power consumption. Thereby, the consumer gets reliable power supply as per their requirement. The contribution of optimal power from FACTS and distributed generation are found and uploaded in the cloud for consumer payment towards power consumption.

References

[1] Birman Kenneth P., Lakshmi Ganesh and Robbert Van Renesse, "White paper running smart grid control software on cloud computing architectures," *Computational Needs Next Generation Electric Grid*, 2011.

[2] Mell Peter and Timothy Grance, "The NIST Definition of Cloud Computing NIST Special Publication, Reports on Computer Systems Technology," National Institute of Standards and Technology, Gaithersburg, MD, USA (2011).

[3] Birman K., A. Bose D. Bakken and C. Hauser, "GridControl: A software platform to support the smart grid," *A Cornell University and Washington State University Research Collaboration*, 2011.

[4] Federal Energy Regulatory Commission, "Principles for efficient and reliable reactive power supply and consumption," FERC Staff Reports, Docket No. AD05-1-000 (2005): 161-162.

[5] Liscouski B. and W. Elliot, "Final report on the august 14, 2003 blackout in the united states and canada: Causes and recommendations," A report to US Department of Energy 40, no. 4, 2004.

[6] El-Samahy, Ismael, Kankar Bhattacharya, Claudio Cañizares, Miguel F. Anjos, and Jiuping Pan, "A procurement market model for reactive power services considering system security," *IEEE Trans. Power Syst. 23*, no. 1, pp. 137-149, 2008.

[7] Fang, Xi, Satya Jayant Misra, Guoliang Xue, and Dejun Yang, "Managing smart grid information in the cloud: opportunities, model, and applications," *IEEE network 26*, no. 4, 2012.

[8] Mehmi, Sandeep, Harsh K. Verma, and A. L. Sangal., "Simulation modeling of cloud computing for smart grid using CloudSim," *J. Electr. Syst. Inform. Technology*, no. 1, pp.159-172, 2017.

[9] Thakur, Jagruti, and Basab Chakraborty, "Intelli-grid: Moving towards automation of electric grid in India," *Renewable and Sustainable Energy Reviews*, pp. 16-25, 2015.

[10] Yigit, Melike, V. CagriGungor, and Selcuk Baktir, "Cloud computing for smart grid applications," *Comput. Networks*, pp. 312-329, 2014.

[11] US Department of Energy. *The Smart Grid: An Introduction.* [Online] available: http://www.oe.energy.gov/DocumentsandMedia/DOE_SG_Book_Single_Pages(1).pdf

[12] Birman Ken, Gregory Chockler and Robbert van Renesse, "Toward a cloud computing research agenda," *ACM SIGACt News*, no. 2, pp. 68-80, 2009

[13] Kumar A., "Reactive Power and FACTS Cost Model's Impact on Nodal Pricing in Hybrid Electricity Markets," *Smart Grid and Renewable Energy*, 2011.

[14] Board, Planning Wing of Tamil Nadu Electricity, *Tamil Nadu electricity board statistics at a glance 1999-2000*, Chennai, India

[15] Danalakshmi D., Kannan S. and Thiruppathy Kesavan V., "Reactive power pricing using cloud service considering wind energy," *Cluster Comput.*, pp. 1-11, 2017.

[16] Mamandur K. R. C. and R. D. Chenoweth, "Optimal control of reactive power flow for improvements in voltage profiles and for real power loss minimization," *IEEE Trans. Power Apparatus Syst.*, pp. 3185-3194, 1981.

[17] Storn Rainer and Kenneth Price,*Differential Evolution simple and efficient adaptive scheme for global optimization over continuous spaces.* Berkeley, International Computer Science Institute, 1995.

[18] Sharma Harish, Jagdish Chand Bansal and K. V. Arya, "Self balanced differential evolution," *J. Comput. Sci.*, no. 2, pp. 312-323, 2014.

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