J. Electrical Systems 20-7s (2024): 348-363

[1]Rahmatul Hidayah,

[2]Ismail Musirin,

[3]Zulkiffli Abdul Hamid

[4]Nor Azwan Mohamed Kamari

[5]Siti Rafidah Abdul Rahim

[6]A.V. Sentil Kumar

Reactive Power Management in Loss and Voltage Control via Integrated Clonal Accelerated Evolutionary Programming

Abstract: - Optimal Reactive Power Dispatch (ORPD) plays a crucial role in maintaining voltage stability, enhance power transfer capability, improve system efficiency, regulate voltages, manage congestion, facilitate renewable energy integration, and achieve cost savings in power systems. This paper presents a new optimization technique for optimal reactive power management in power transmission system, called Integrated Clonal Accelerated Evolutionary Programming (ICAEP) algorithm to optimize the reactive power to be dispatched by the generator buses under 3 scenarios with cases. The ICAEP was developed based on hybridization of the traditional Artificial Immune System (AIS) and Evolutionary Programming (EP). The two cases demonstrate the effect of reactive load increment at the chosen load buses; while the three scenarios represent the ORPD schemes which indicate the involvement of generator buses either 3 generators, 4 generators or 5 generators. Implementation of ICAEP outperformed AIS and EP in both objective functions either in minimum voltage maximization or power loss minimization, involving all the cases under the three scenarios. The performance of the ICAEP is evaluated on the IEEE 30-bus test system. The results would be beneficial to power system operators and planning expansion and knowing the status of their systems in their utilities. The developed optimization engine is also robust and feasible for further optimization problem solving initiatives.

Keywords: Integrated Clonal Accelerated Evolutionary Programming; Reactive Power Dispatch; Loss Minimization; optimization; Optimal sizing

I. INTRODUCTION

Due to the rapidly evolving energy landscape, the efficient and reliable operation of power systems is paramount. Power utilities and grid operators face the challenge of not only supplying the required active power to meet the demand but also managing the reactive power component of the electrical system. Reactive power, while not directly contributing to useful work output, is essential for maintaining voltage stability, supporting magnetic fields, and ensuring the overall integrity of the grid. Reactive Power Management plays a critical role in maintaining the

---

[1 ,2,3]Power System Operation Computational Intelligence Research Group (POSC), School of Electrical Engineering, College of Engineering, Universiti Teknologi MARA (UiTM)

40450 Shah Alam, Selangor, Malaysia.

e-mail: rhidayah@uitm.edu.my, ismailbm@uitm.edu.my, zulkiffl9947@uitm.edu.my

[4]Faculty of Engineering and Built Environment, The National University of Malaysia, Malaysia.

[5]Faculty of Electrical Engineering Technology, Universiti Malaysia Perlis, Kampus Pauh Putra, 02600, Arau, Perlis, Malaysia

e-mail: rafidah@unimap.edu.my

[6]Hindusthan College of Arts and Science, Coimbatore, India.

Email: avsenthilkumar2007@gmail.com

**Corresponding author: ismailbm@uitm.edu.my

quality and reliability of electrical power supply. It involves the careful control and coordination of reactive power sources and devices to ensure that voltage levels remain within acceptable limits, reducing the risk of voltage collapses, equipment damage, and even blackouts. Effective management of reactive power enhances the system's resilience against disturbances and enables a more flexible and dynamic grid. One of the key tools in Reactive Power Management is Optimal Reactive Power Dispatch (ORPD). ORPD leverages advanced optimization techniques and algorithms to determine the optimal settings for reactive power sources such as generators, capacitors, and reactors. In this context, the ORPD emerges as a challenging nonlinear problem in power system engineering. By optimizing the distribution of reactive power resources, ORPD aims to minimize losses, improve voltage profiles, and enhance the overall efficiency of the power system. This approach goes beyond traditional rule-based methods, allowing for a more adaptive and responsive control strategy that can adapt to varying load conditions and system configurations. By redistributing reactive power generation, power system engineers can reduce the risk of blackouts and equipment malfunctions. ORPD involves a combination of techniques and measures to optimize the control, monitoring and compensation of reactive power in power systems. Reactive power control equipment like capacitors, reactors, synchronous condensers, and SVC may be used in ORPD approaches. These devices help inject or absorb reactive power as needed to regulate voltage levels and compensate for fluctuations in reactive power demand.

Various methods have been developed to solve the problem over the years. For challenges involving global optimization, several classic as well as meta-heuristic techniques including Evolutionary Programming [1], Differential Evolution (DE) [2], Particle Swarm Optimization (PSO) [3-6], have been developed in recent years. In the last decades, computational intelligence-based techniques have been proposed for solving reactive power planning problems especially in the ORPD [7]. The ORPD problem has been presented as both single objective and multi-objective optimization problems. Single objective ORPD using Particle Swarm Optimization (PSO) is proposed in [8] for minimizing the total costs which includes the energy loss of transmission network and cost of adjusting the control devices. A multi-agent based PSO (MAPSO) is presented in [9] to solve the ORPD problems. An ORPD considering static voltage stability and voltage deviations is proposed using seeker optimization algorithm (SOA) in [10]. The SOA is based on the concept of simulating the act of human searching, where search direction is based on the empirical gradient. In [11], management and rescheduling of reactive power support is treated as an ORPD problem. The objective function is to maximize voltage stability margin, while maintaining the the economic dispatch of active power, by rescheduling the reactive power injections from synchronous generators and synchronous condensers. Harmony search algorithm (HSA) is proposed in [12] to solve the ORPD problem. An optimal reactive power dispatch strategy considering the steady-state voltage stability is studied in [13]. An evolutionary-based approach which employs differential evolution (DE) algorithm for optimal setting of ORPD control variables is proposed in [14]. In [15], restoring the desired voltage security margin based on demand response using load-to-source impedance ratio index and PSO is presented. This method is applied to optimize the reactive power dispatch, taking into consideration the reactive power requirement at the point of common coupling, while active power losses are minimized in the wind farm. In [16], an objective function based on a voltage stability index is introduced for ORPD problem.

Although extensive meta-heuristic techniques have been proposed by many researchers in solving the optimal reactive power dispatch, each of the individual pure techniques has its own merits and demerits. As an example, population-based computing techniques such as GA, EP, PSO and DE may not assure global optimality, but it still provides good near-optimal solution in an acceptable computational time. Recently, hybridization of meta-heuristic techniques has gained popularity in research work. The hybrid meta-heuristic is referred to as the algorithm that combines various algorithmic ideas from several branches of artificial intelligence approaches. The most important motivation of doing the hybridization of different algorithmic concepts has been to obtain better performing systems that exploit and combine advantages of the individual pure strategies. It is believed that the new hybridization approach will benefit from its synergy. Choosing an adequate combination of multiple algorithmic concepts is often the key for achieving top performance in solving many hard optimization problems. Thus, the hybridization of intelligence techniques has grown its popularity of this line of research specifically in solving the ORPD in the recent years.

Modified cuckoo search algorithm: A novel method to minimize the fuel cost in [17] to solve fuel cost problem. In [18], the performance of different constraint handling methods on ORPD are evaluated. An algorithm combining modified teaching–learning algorithm (TLA) and double DE algorithm is introduced in [19] to handle the ORPD problem. Also, in [20], a heuristic algorithm based on hybrid modified imperialist competitive algorithm and invasive weed optimization is proposed for dealing with the ORPD problem.

In [21], the authors address the problem of ORPD as a non-linear, mixed integer optimization problem. The study introduces a new modified DE approach to settle the RPD control variables to reduce power system losses and enhance voltage profile and system security. As reported in [22], the researchers used EP in order to improve RPD and voltage control in power systems. EP has been applied to the IEEE 30-bus system for global optimization in power systems. Comparing it to a gradient-based method, EP shows potential for enhancing the economic efficiency of the power system. Many hybrid algorithms have been employed recently to address the reactive power optimization problem in power systems. Hybrid methods offer the advantage of fast convergence speed while being able to search for the global optimum over a wide range. However, the current ORPD approaches in use may not effectively tackle the challenge of improving the voltage profile in power networks.

This paper presents a hybrid computational intelligence-based technique namely ICAEP for optimal sizing of the reactive power support to address the ORPD problems. Validation was conducted on a reliability test system (RTS) namely the IEEE 30-bus system and its performance in maintaining the voltage profile within the acceptable limits, improving the power losses as well as the voltage stability index are compared with the classical EP and AIS. Results from the proposed ICAEP reveals its superiority over the traditional EP and AIS in addressing the loss and voltage control study.

II. PROBLEM FORMULATION

A. *Objective Function*

ORPD plays a critical role in addressing multiple aspects of power system operation, including voltage control and power loss minimization. To maintain appropriate voltage levels throughout the power system to ensure stable operation and reliable performance by strategically adjusting the reactive power output of generators and the placement of reactive power compensating devices, ORPD helps regulate voltage levels within acceptable limits. Proper voltage control prevents over-voltages and under-voltages, which can damage equipment and disrupt service to consumers. ORPD ensures that the system operates within the desired voltage range, contributing to efficient and reliable power delivery.

Reactive power losses occur due to the flow of reactive current through network components such as transmission lines and transformers. These losses contribute to inefficiencies and increased energy costs. ORPD optimizes the allocation of reactive power resources to minimize these losses. By strategically managing the flow of reactive power and reducing the magnitude of reactive currents, ORPD reduces power losses and improves overall system efficiency.

Coordinating the control of voltage within power transmission systems represents a critical optimization challenge. Inadequate sizing of these compensating devices can result in undesirable situations of both under-compensation and over-compensation. Thus, a robust and dependable optimization methodology is essential to establish an accurate compensation strategy.

B. *Objective Function*

This section describes the fitness equations and objective functions solved in this study. Relevant constraints are also elaborated.

i. *Voltage Profile Improvement*

The objective function in this study is to improve voltage in an electric power system by taking V_m as the fitness value. The problem formulation of ORPD installation was started by finding the optimal location, size, and control settings of the OPRD to improve the power system performance, such as enhancing power system stability, reducing power losses, improving voltage profile, and increasing transmission capacity. The objective function is the maximization minimum voltage in the system, given by (1).

$$OF = max(V_{min}) \quad (1)$$

ii. Power Loss Minimization

The real power losses $Ploss$ (MW) is the next fitness equation, while the objective function is the minimization of real power loss. The equations are given in (2) and (3) respectively.

$$O.F = Min(P_{loss}) \quad (2)$$

$$P_{loss} = \sum_{i=1}^{N} g_k \left(V^2{}_i + V^2{}_j - 2V_iV_j cos\theta_{ij} \right) \quad (3)$$

Where;

N : Number of transmission line

g_k: Conductance at line k

V_i : Voltage magnitude at end of bus i

V_j : Voltage magnitude at end of bus j

θ_{ij}: Voltage phase angle at end of bus i/j

C. Constraints Equation

Two constraints equations are considered involving the equality constraint and inequality constraint. Constraints on inequality include the ranges of voltage magnitudes, the location of the SVC and the injections of reactive powers.

$$0.95 < V_i < 1.05 \quad (4)$$

The equality requirement and the inequality constraint are the restrictions that cause issues in this optimization. The balance of active power flow in each bus (except the slack bus) is equality constraint and the formulated in the equation below is balanced of reactive power flow:

$$P_{gi} - P_{di} - V_i \sum V_j \left(G_{ij} cos\theta_{ij} + B_{ij} sin\theta_{ij} \right) = 0 \quad (5)$$

$$Q_{gi} - Q_{di} - V_i \Sigma V_j \left(G_{ij} cos\theta_{ij} + B_{ij} sin\theta_{ij} \right) = 0 \quad (6)$$

Where,

P_{gi}: Active power on generator bus

Q_{gi}: Reactive power generator bus

P_{di} : Active power on load bus

Q_{di}: Reactive power on load bus

III. OVERVIEW OF THE PROPOSED METHOD

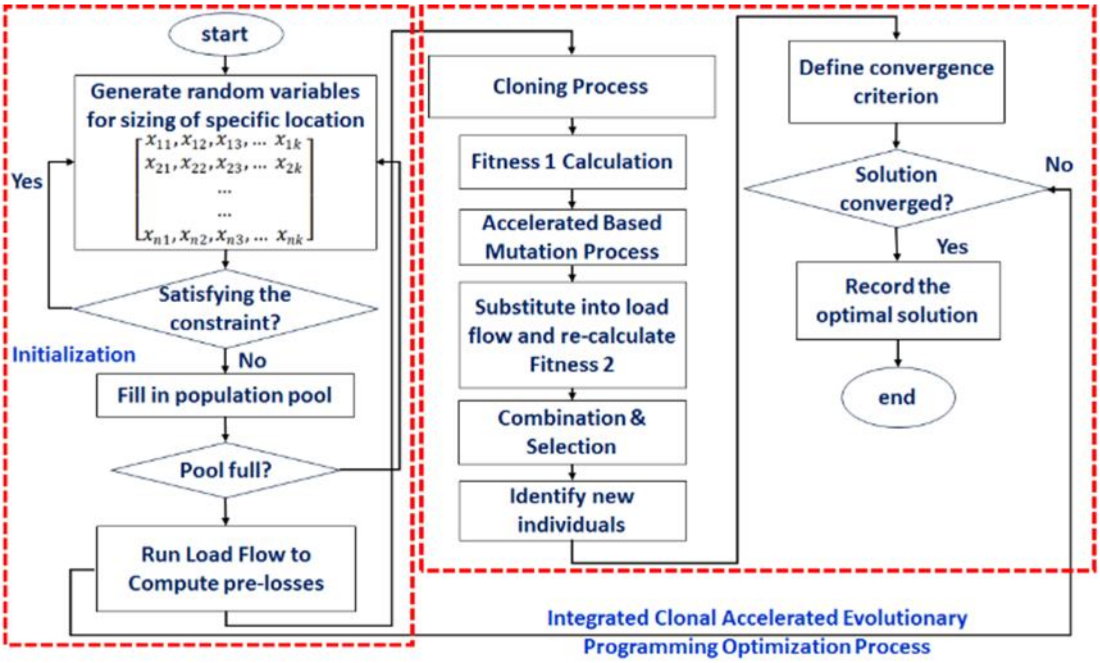

Figure 1: Flowchart of ICAEP

In the field of electrical power system engineering, numerous optimization techniques have been applied to complex problems [9]. One widely utilized method is EP, which has proven effective in optimizing fitness function represented by mathematical equations. EP encompasses several steps including initialization, mutation, and reproduction to iteratively improve the solutions. In a specific study, EP has been employed to address the challenge of optimal sizing in order to enhance the voltage profile and minimize power losses in power systems.

The ICAEP algorithm is a newly developed technique, integrating both EP and AIS in its development. The EP initialization step is implemented due to its chaotic property of population generation, allowing a solution to be identified from multiple approaches. The mutation process is accelerated before it is paired with AIS cloning process which benefits from its exploration capability and converge onto the best individual in the population to obtain the optimal solution. The flowchart of ICAEP algorithm is shown in Figure 1. ICAEP intends to optimize the sizing of reactive power resources, resulting in improved voltage profiles and reduced power losses while improving the convergence speed in electrical power systems. The inclusion of acceleration allows for more effective exploration of the solution space and enhances the algorithm ability to avoid local optima, ultimately contributing to finding better solutions. The detailed ICAEP algorithm development is described in the following steps: -

Step 1: Initialization

In this process, 20 individuals of reactive power support as the control variables will be randomly generated. In general, the control variables in this study are the sizing of reactive power to be dispatched by the generator buses. In this study, the control variables depend on the number of generators involved in the ORPD scheme. This will be explained in detail in the results and discussion since several cases are considered in this study.

$$Initial\ population = \begin{bmatrix} x_{11} & x_{12} & x_{13} \cdots & x_{1k} \\ x_{21} & x_{22} & x_{23} & x_{2k} \\ \vdots & \vdots & \vdots & \vdots \\ x_{n1} & x_{n2} & x_{n3} \cdots & x_{nk} \end{bmatrix} \quad (7)$$

Variable *n* represents the number of individuals of the participating control variables. In this study, 20 individuals are generated for each control variable, making the population size to be [*n* column by *k* column of control variables]. In this study, *n* is 20.

Step 2: Cloning Process

Cloning is a process of multiplying the initial population of parents. The clone population x_{nk_cln} will be assigned back to the generator. The cloning process is conducted to allow the algorithm learns repetitive several identical individuals so that the whole population can be multiplied and help the optimization process due to the individuals similarity.

Step 3: Fitness 1 Calculation

In this step. The fitness function will be evaluated using the cloning population and the output is stored in an array called *out1*. In this study, the fitness are power loss and minimum voltage in the system, conducted independently in single objective optimization process.

Step 4: Accelerated Mutation

Next step, the clonal population will undergo mutation process that has been accelerated to breed the offspring. In this step, the offspring values are modified using a parameter "lambda" within the range of 0 to 0.9. The mutation process involves adjusting the offspring solutions to enhance their convergence towards improved solutions.

$$V_{acc}^{G} = V_{best}^{G} + \mathrm{l}(V_{best}^{G} - V^{G}) \qquad (8)$$

The symbol *l*, serves as the accelerated coefficient in the mutation process which expedite the whole optimization process.

Step 5: Fitness 2 Calculation

The fitness value of the offspring is evaluated again using load flow calculations and the resulting value is stored in another array, called *out2*. A loop is started to iterate over 20 accelerated solutions to improve the optimization process even further. The reactive power injections are updated based on the current accelerated solution inside each cycle, allowing for dynamic modifications. This adjustment process ensures that the offspring for reactive power injections align with the accelerated solution being evaluated. Using this iterative technique, the algorithm explores multiple potential solutions, improving and adjusting the reactive power injections to optimize the overall performance of the system.

Step 6: Combination and Selection

The population embedded in the first array, *out1* called as fitness 1 (*out1*) and fitness 2 (*out2*) from the population of the offsprings are combined into a single matrix called *out_all*. This makes the combined population size double within the same number of control variables. The selection process is conducted to identify the survivors for the next evolution. These survivors are the parents for the next cycle or evolution. It is done by performing elitism process where all the individuals are sorted in accordance with the best fitness. The best fitness depends on the objective function. For minimization process as the objective function, the lowest fitness value will be ranked at the top of the list. Or in other words, these individuals are sorted in ascending order based on fitness values. For the case of V_{min} maximization, the individuals are sorted in accordance with the highest V_{min} value, where they are sorted in descending order.

Step 7: Convergence Test

Convergence test ensures the stopping criterion of the optimization process. The convergence test was done by checking if the difference between the maximum and minimum fitness values is below a threshold. If the convergence is achieved, terminate the optimization process. Otherwise, the process will be repeated. This statement can be mathematically written as: -

$$fitness_{max} - fitness_{min} \leq 0.0001 \qquad (9)$$

IV. RESULTS AND DISCUSSION

The newly proposed ICAEP optimization algorithm has been tested on the standard IEEE 30-bus test system shown in Figure 2 to evaluate the optimal sizing of the ORPD and the effectiveness of the proposed algorithm. Two different cases with three scenarios have been considered as follows:

Case 1: Bus 29 was subjected to load reactive load variation between 5 MVar to 25 MVar.

Case 2: Bus 30 was subjected to load reactive load variation between 5 MVar to 25 MVar.

This condition was evaluated for specific locations of ORPD scheme where multiple scenarios have been assessed.

Scenario 1: ORPD for three generators at Buses 5, 8 and 11; denoted by Q_{g5}, Q_{g8} and Q_{g11}.

Scenario 2: ORPD for four generators at Buses 2, 5, 8 and 11 denoted by Q_{g2}, Q_{g5}, Q_{g8} and Q_{g11}.

Scenario 3: ORPD for five generators at Buses 2, 5, 8, 11 and 13 denoted by Q_{g2}, Q_{g5}, Q_{g8}, Q_{g11} and Q_{g13}.

In each case and scenario, the performance of the system, such as minimum voltage (V_{min}), total real power loss (P_{Loss}) and the optimised sizing of the reactive power to be dispatched for the ORPD scheme are optimized. The performance of the ICAEP is compared to that of the EP and AIS algorithms in terms of determining the improved minimum voltage value in the system and minimizing the power losses while meeting the system's constraint. The sizing of the ORPD is evaluated for each scenario and the results before and after the optimization are also compared.

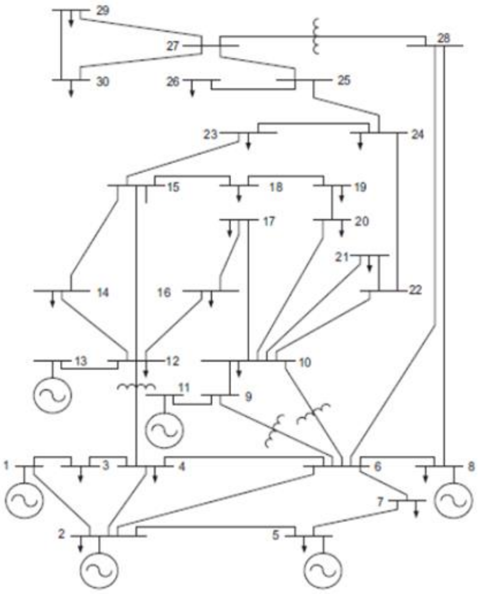

Figure 2: IEEE 30-bus test system

A. Maximization of Voltage

Maximization of minimum voltage in the system is the first objective function in this study. Table 1 and Table 2 tabulate the results for minimum voltage maximization with the ORPD scheme.

Case 1: Reactive Load Variation at Bus 29

Table 1 tabulates the results of the minimum voltage improvement for Case 1 when Q_{d29} was subjected to reactive load variations between 5 MVar to 25 MVar. In Scenario 1, generally, the increment of reactive power loading at

Bus 29 reduces the voltage from 0.9737 p.u. to 0.8179 p.u.. With the implementation of ORPD into the system, minimum voltage in the system is increased, solved using all the three optimization techniques, EP, AIS and ICAEP. For instance, at Q_{d29} = 25 MVAR, EP increases the minimum voltage in the system from 0.8179 p.u. to 0.9700 p.u. while AIS improves its value to 1.0062, and the proposed ICAEP improves its value to 1.0116 p.u.. It is shown that ICAEP achieves the highest value as compared to EP and AIS. This reveals the superiority of ICAEP over AIS and EP. The amount of reactive power to be dispatched by the generators are Q_{g5} = 79.5064 MVAR, Q_{g8} = 125.6034 MVAR and Q_{g13} = 114.2270 MVAR when solved using ICAEP as highlighted in the table.

Table 1: Case 1: Voltage profile with load variation at Q_{d29}

	Techniques	Q_{d29} (MVAR)	Before	After	Q_{g2} (MVar)	Q_{g5} (MVar)	Q_{g8} (MVar)	Q_{g11} (MVar)	Q_{g13} (MVar)
Scenario 1	EP	5	0.9737	1.0352	-	66.8076	85.0228	-	47.6043
		10	0.9436	1.0058	-	74.5359	79.6429	-	63.0841
		15	0.9064	0.9815	-	78.5243	78.4481	-	76.6791
		20	0.8651	0.9674	-	76.4899	77.8853	-	67.2613
		25	0.8179	0.97	-	76.2144	78.7522	-	70.9125
	AIS	5	0.9737	1.035	-	88.3425	139.5605	-	126.9211
		10	0.9436	1.0298	-	85.3976	134.9085	-	122.6904
		15	0.9064	1.0245	-	82.453	130.2565	-	118.4597
		20	0.8651	1.0116	-	79.5082	125.6045	-	114.229
		25	0.8179	1.0062	-	76.5635	120.9525	-	109.9983
	ICAEP	5	0.9737	1.0476	-	91.2851	144.2113	-	131.1491
		10	0.9436	1.035	-	88.3403	139.5593	-	126.9188
		15	0.9064	1.0298	-	85.3957	134.9073	-	122.6882
		20	0.8651	1.0245	-	82.4504	130.2553	-	118.458
		25	0.8179	1.0116	-	79.5064	125.6034	-	114.227
Scenario 2	EP	5	0.9737	1.036	44.6367	86.0361	102.8683	-	134.7775
		10	0.9436	1.0299	43.3239	83.5057	99.8428	-	130.8135
		15	0.9064	1.0221	41.6828	80.3426	96.0608	-	125.8584
		20	0.8651	1.0173	40.6971	78.4439	93.7927	-	122.8853
		25	0.8179	0.9944	36.1023	69.5873	83.2032	-	109.0111
	AIS	5	0.9737	1.0466	46.9328	90.4636	108.1625	-	141.7137
		10	0.9436	1.0391	45.2918	87.3005	104.3806	-	136.7586
		15	0.9064	1.0314	43.6508	84.1374	100.5987	-	131.8036
		20	0.8651	1.0236	42.0091	80.9736	96.8183	-	126.8485
		25	0.8179	1.0157	40.3688	77.8113	93.0349	-	121.8936
	ICAEP	5	0.9737	1.0496	47.5885	91.7278	109.6766	-	143.6961
		10	0.9436	1.0421	45.9475	88.5654	105.8949	-	138.7411
		15	0.9064	1.0345	44.3066	85.4024	102.1129	-	133.786
		20	0.8651	1.0268	42.6655	82.2388	98.3311	-	128.8305
		25	0.8179	1.0189	41.0245	79.0758	94.5491	-	123.8754
	EP	5	0.9737	1.0344	58.8449	38.2665	66.6062	83.7451	60.9694
		10	0.9436	1.0108	58.8445	29.9457	66.6049	65.5375	60.9671
		15	0.9064	0.9922	52.3066	29.9477	52.5838	65.5392	60.9685
		20	0.8651	0.9897	52.3058	29.1143	52.5821	63.7178	60.9671
		25	0.8179	0.9891	45.7676	29.9461	52.5822	65.5383	60.9671
		5	0.9737	1.0317	57.8109	71.5664	65.1494	69.3939	50.5289

Scenario 3	AIS	10	0.9436	1.0152	19.0201	26.1137	35.924	158.993	38.9195
		15	0.9064	1.0077	52.3116	31.1989	63.1051	68.2729	60.974
		20	0.8651	0.9838	22.1613	68.5323	47.6712	34.8294	75.2732
		25	0.8179	0.9534	28.0794	38.4945	53.1982	63.4475	32.9647
	ICAEP	5	0.9737	1.0467	98.7396	104.556	7.2647	104.0324	55.4949
		10	0.9436	1.0377	89.7633	104.5569	7.2649	104.0334	50.45
		15	0.9064	1.0255	56.7895	36.6858	118.3941	56.8046	29.2733
		20	0.8651	1.0177	88.4684	31.3596	52.3666	88.1451	47.7709
		25	0.8179	0.9945	92.5637	30.9687	49.8445	61.7874	51.4684

In Scenario 2, 4 generators participate in the ORPD scheme involving generators at Buses 2, 5, 8 and 13. In general, the implementation of ORPD involving 4 generators managed to increase the minimum voltage in the system, solved using the three optimization techniques regardless of the reactive power loading. For instance, at Q_{d29} = 25 MVAR, EP increases the minimum voltage from 0.8179 p.u. to 0.9944 p.u., while AIS increases its value to 1.0157 p.u., and the proposed ICAEP increases its value to 1.0189 p.u.. Similar observation is experienced as those in Scenario 1. It is worth mentioning that ICAEP continues to outperform both EP and AIS in achieving the highest voltage value. At this loading condition, the four generators require Q_{g2} = 41.0245 MVAR, Q_{g5} = 79.0758 MVAR, Q_{g8} = 94.5491 MVAR and Q_{g13} = 123.8754 MVAR to achieve the highest voltage value.

In Scenario 3, all the 5 generators in the system participate in the ORPD scheme involving generators at Buses 2, 5, 8, 11 and 13. The implementation of ORPD involving all the 5 generators managed to increase the minimum voltage value in the system, solved using the three optimization techniques. For instance, at Q_{d29} = 25 MVAR, EP increases the voltage value from 0.8179 p.u. to 0.9891 p.u., while AIS increases its value to 0.9534 p.u., and the proposed ICAEP increases its value to 0.9945 p.u.. Similar observation is experienced as those in Scenario 1 and Scenario 2. It is worth mentioning that ICAEP continues to outperform both EP and AIS in achieving the highest voltage value. At this loading condition, the five generators require Q_{g2} = 92.5637 MVAR, Q_{g5} = 30.9687 MVAR, Q_{g8} = 49.8445 MVAR, Q_{g11} = 61.7874 and Q_{g13} = 51.4684 MVAR to achieve the lowest power loss. The results for other reactive power loading can also be referred to in the same table using all the optimization techniques.

Table 2: Case 2: Voltage profile with load variation at Q_{d30}

	Techniques	Q_{d30} (MVAR)	Before	After	Q_{g2} (MVar)	Q_{g5} (MVar)	Q_{g8} (MVar)	Q_{g11} (MVar)	Q_{g13} (MVar)
Scenario 1	EP	5	0.9728	1.0298	-	85.3976	134.9085	-	122.6904
		10	0.9326	1.0224	-	81.2732	128.3945	-	116.7653
		15	0.891	1.0084	-	77.7396	122.8122	-	111.6886
		20	0.8438	0.9851	-	70.6723	111.6474	-	101.5352
		25	0.7881	0.9758	-	64.783	102.3435	-	93.0739
	AIS	5	0.9728	1.0313	-	91.2872	144.2126	-	131.1518
		10	0.9326	1.0298	-	85.3957	134.9073	-	122.6882
		15	0.891	1.0185	-	88.3425	139.5605	-	126.9211
		20	0.8438	0.9891	-	76.5635	120.9525	-	109.9983
		25	0.7881	0.9777	-	70.674	111.6484	-	101.5369
	ICAEP	5	0.9728	1.0352	-	66.8076	85.0228	-	47.6043
		10	0.9326	1.0313	-	45.4288	58.6334	-	77.3396
		15	0.891	1.0255	-	37.37	66.2374	-	62.6215
		20	0.8438	1.0209	-	55.3519	61.0716	-	51.0848
		25	0.7881	1.0175	-	71.412	71.0659	-	29.239
	EP	5	0.9728	1.0197	44.6367	86.0361	102.8683	-	134.7775
		10	0.9326	1.0134	43.3239	83.5057	99.8428	-	130.8135
		15	0.891	1.0055	41.6828	80.3426	96.0608	-	125.8584

Scenario 2		20	0.8438	1.0006	40.6982	78.4447	93.7917	-	122.8854
		25	0.7881	0.9941	39.3843	75.9135	90.7671	-	118.9212
	AIS	5	0.9728	1.0305	46.9328	90.4636	108.1625	-	141.7137
		10	0.9326	1.0228	45.2918	87.3005	104.3806	-	136.7586
		15	0.891	1.015	43.6508	84.1374	100.5987	-	131.8036
		20	0.8438	1.0022	41.0245	79.0758	94.5491	-	123.8754
		25	0.7881	0.999	40.3688	77.8113	93.0349	-	121.8936
	ICAEP	5	0.9728	1.0335	47.5885	91.7278	109.6766	-	143.6961
		10	0.9326	1.0259	45.9475	88.5654	105.8949	-	138.7411
		15	0.891	1.0181	44.3066	85.4024	102.1129	-	133.786
		20	0.8438	1.0103	42.6655	82.2388	98.3311	-	128.8305
		25	0.7881	1.0022	41.0245	79.0758	94.5491	-	123.8754
Scenario 3	EP	5	0.9728	1.0184	58.8485	38.2694	66.6089	83.7471	60.9726
		10	0.9326	1.0143	49.041	38.2695	59.5991	83.7483	68.5947
		15	0.891	1.0079	52.308	38.2666	59.5954	83.7454	60.9707
		20	0.8438	0.9698	80.785	83.6436	5.7492	83.2246	40.3582
		25	0.7881	0.9652	49.041	29.9497	52.5872	65.5416	53.351
	AIS	5	0.9728	1.0253	41.2268	79.0853	59.23	44.7874	6.8956
		10	0.9326	1.0167	61.9279	23.1786	30.5471	65.1505	35.8282
		15	0.891	0.9911	52.3116	31.1981	63.1049	68.2723	60.974
		20	0.8438	0.9721	22.1648	68.5345	47.6752	39.4761	75.2767
		25	0.7881	0.9653	54.3074	50.9454	84.1202	28.761	41.5515
	ICAEP	5	0.9728	1.0482	67.8842	78.1169	112.1602	44.1006	51.9393
		10	0.9326	1.0341	75.6368	113.9646	43.8353	28.405	98.2507
		15	0.891	1.0271	72.5389	114.9355	106.6258	26.8153	30.6299
		20	0.8438	1.0127	25.006	87.5719	92.4216	95.1968	12.5342
		25	0.7881	1.0014	88.4684	31.3595	52.3665	88.1447	47.7708

Case 2: Reactive Load Variation at Bus 30

In Case 2, reactive load variation was subjected to Bus 30 as the second tested bus. Similar three scenarios were also considered for this study with load being reactively increased from 5 MVAR to 25 MVAR. The results are tabulated in Table 2 to demonstrate the voltage increment at all the load increment, optimized using the 3 optimization techniques.

In Scenario 1, generally, the increment of reactive power loading at Bus 30 reduces the voltage from 0.9728 p.u. to 0.7881 p.u.. With the implementation of ORPD into the system, minimum voltage in the system is increased, solved using all the three optimization techniques, EP, AIS and ICAEP. For instance, at Qd_{30} = 25 MVAR, EP increases the minimum voltage in the system from 0.7881 p.u. to 0.9758 p.u.. while AIS improves its value to 0.9777, and the proposed ICAEP improves its value to 1.0175 p.u.. It is shown that ICAEP achieves the highest value as compared to EP and AIS. This reveals the superiority of ICAEP over AIS and EP. The amount of reactive power to be dispatched by the generators are Q_{g5} = 71.4120 MVAR, Q_{g8} = 71.0659 MVAR and Q_{g13} = 29.2390 MVAR when solved using ICAEP as highlighted in the table.

In Scenario 2, 4 generators participate in the ORPD scheme involving generators at Buses 2, 5, 8 and 13. In general, the implementation of ORPD involving 4 generators managed to increase the minimum voltage in the system, solved using the three optimization techniques regardless of the reactive power loading. For instance, at Q_{d30} = 25 MVAR, EP increases the minimum voltage from 0.7881 p.u. to 0.9941 p.u., while AIS increases its value to 0.9990 p.u., and the proposed ICAEP increases its value to 1.0022 p.u.. Similar phenomenon is observed here as those in Scenario 1. ICAEP continues to outperform both EP and AIS in achieving the highest voltage value. At this loading condition, the four generators require Q_{g2} = 41.0245 MVAR, Q_{g5} = 79.0758 MVAR, Q_{g8} = 94.5491 MVAR and Q_{g13} = 123.8754 MVAR to achieve the highest voltage value.

Table 3. Case1: Power Losses (P_{Loss}) with load variations at Q_{d29}

	Techniques	Q_{d29} (MVAR)	Before (MW)	After (MW)	Q_{g2} (MVar)	Q_{g5} (MVar)	Q_{g8} (MVar)	Q_{g11} (MVar)	Q_{g13} (MVar)
Scenario 1	EP	5	17.2784	17.2084	-	48.3293	54.7427	-	160.0028
		10	18.1164	17.9801	-	50.0893	166.0028	-	185.251
		15	18.6192	18.2421	-	50.1318	54.2563	-	164.6007
		20	19.3855	19.0367	-	80.4876	62.2606	-	103.8897
		25	20.526	20.2521	-	64.1823	91.236	-	67.8687
	AIS	5	17.2784	15.1452	-	52.1122	77.431	-	12.0263
		10	18.1164	16.0011	-	65.2505	56.8623	-	37.5962
		15	18.6192	17.1021	-	69.5916	59.5892	-	28.4406
		20	19.3855	17.4336	-	79.3586	43.4418	-	54.6787
		25	20.526	18.0013	-	35.3159	82.1194	-	41.5403
	ICAEP	5	17.2784	10.0421	-	29.2052	13.4037	-	20.0948
		10	18.1164	10.2123	-	46.7517	14.1336	-	6.8134
		15	18.6192	11.2112	-	33.1665	15.2234	-	34.8008
		20	19.3855	11.4125	-	31.6429	21.7563	-	25.1042
		25	20.526	13.8781	-	54.1611	40.3912	-	9.6455
Scenario 2	EP	5	17.2784	16.7121	47.2112	88.3111	54.7427	-	90.0028
		10	18.1164	17.1981	64.5433	70.0393	52.3218	-	65.251
		15	18.6192	18.0021	52.5768	63.4587	80.4576	-	64.6007
		20	19.3855	18.2541	75.4444	67.7632	64.1823	-	73.6597
		25	20.526	19.6512	21.8798	88.5675	102.3243	-	67.8687
	AIS	5	17.2784	14.5456	79.4354	52.1122	77.431	-	12.0263
		10	18.1164	16.1101	67.0989	65.2532	56.8623	-	37.5962
		15	18.6192	17.5621	166.0028	48.5546	59.5892	-	28.4406
		20	19.3855	17.1221	54.2563	65.3876	43.4418	-	54.6787
		25	20.526	18.1921	62.2606	35.3159	82.1194	-	41.5403
	ICAEP	5	17.2784	10.0465	98.3454	29.2052	13.4037	-	20.0948
		10	18.1164	10.4213	101.3241	46.7517	14.1336	-	36.8134
		15	18.6192	11.2128	87.3421	33.1665	15.2234	-	34.8008
		20	19.3855	12.1087	47.3434	31.6429	21.7563	-	25.1042
		25	20.526	13.7678	32.9856	24.1691	40.3912	-	9.6455
Scenario 3	EP	5	17.2784	17.5992	56.4376	48.3293	54.7427	76.7878	76.89
		10	18.1164	18.1211	88.4354	52.0893	166.0028	75.5678	65.251
		15	18.6192	18.4551	82.2312	57.1318	54.2563	87.7676	84.6057
		20	19.3855	19.4323	78.3501	84.4876	62.2606	56.4565	93.8897
		25	20.526	20.5454	71.1212	74.1823	91.236	86.5452	67.8687
	AIS	5	17.2784	15.5412	83.3332	52.1122	77.431	89.6785	12.0263
		10	18.1164	16.3121	67.3232	65.2505	56.8623	97.5654	37.5962
		15	18.6192	17.1001	59.5476	69.5916	54.2123	67.6567	28.4406
		20	19.3855	17.6767	43.4148	79.3586	51.4351	54.4567	54.6787
		25	20.526	18.2112	82.1154	35.3159	50.3243	91.0002	41.5403
	ICAEP	5	17.2784	10.0098	29.2052	67.5698	13.4037	67.5467	20.0948
		10	18.1164	10.2003	46.7517	76.7654	14.4356	37.6545	46.8134
		15	18.6192	11.5432	33.1665	67.1123	15.2234	87.5676	34.8008
		20	19.3855	12.2198	32.4354	31.6429	21.7563	78.5454	25.1042

	25	20.526	12.8786	65.8791	24.1611	39.3132	65.7558	54.6455

In Scenario 3, all the 5 generators in the system participate in the ORPD scheme. The implementation of ORPD involving all the 5 generators managed to increase the minimum voltage value in the system using all the three optimization techniques. For instance, at Q_{d30} = 25 MVAR, EP increases the voltage value from 0.7881 p.u. to 0.9652 p.u., while AIS increases its value to 0.9653 p.u., and the proposed ICAEP increases its value to 1.0014 p.u.. Similar observation is experienced as those in Scenario 1 and Scenario 2. ICAEP maintains to outperform both EP and AIS in achieving the highest voltage value. At this loading condition, Q_{g2} = 88.4684 MVAR, Q_{g5} = 31.3595 MVAR, Q_{g8} = 52.3665 MVAR, Q_{g11} = 88.1447 and Q_{g13} = 47.7708 MVAR to achieve the highest voltage value. The results for other reactive power loading can also be referred to in the same table using all the optimization techniques.

In summary ICAEP managed to achieve the highest voltage increment in all cases regardless of the reactive load increment for all cases in the tested scenarios.

B. *Power Losses Minimization*

The proposed algorithm was executed with optimal sizing of reactive power to minimize the real power losses as the objective function. In this case, three scenarios are considered as those introduced in the part of this section. Reactive load variation was subjected to Bus 29. In Scenario 1, 3 generators participate in the ORPD scheme involving generators at Buses 5, 8 and 13. In general, the implementation of ORPD involving 3 generators managed to reduce the total power loss in the system, solved using the three optimization techniques regardless of the reactive power loading. For instance, at Q_{d29} = 25 MVAR, EP reduces the power loss from 20.5260 MW to 20.2521 MW, while AIS reduces its value to 18.0013 MW, and the proposed ICAEP reduces its value to 13.8781 MW. It is shown that ICAEP achieves the lowest power loss as compared to EP and AIS. This reveals the superiority of ICAEP over AIS and EP. The amount of reactive power to be dispatched by the generators are Q_{g5} = 54.1611 MVAR, Q_{g8} = 40.3912 MVAR and Q_{g13} = 9.6455 MVAR when solved using ICAEP as highlighted in the table. The results for other reactive power loading can also be referred to in the same table using all the optimization techniques.

In Scenario 2, 4 generators participate in the ORPD scheme involving generators at Buses 2, 5, 8 and 13. In general, the implementation of ORPD involving 4 generators managed to reduce the total power loss in the system, solved using the three optimization techniques regardless of the reactive power loading. For instance, at Q_{d29} = 25 MVAR, EP reduces the power loss from 20.5260 MW to 19.6512 MW, while AIS reduces its value to 18.1921 MW, and the proposed ICAEP reduces its value to 13.7678 MW. Similar observation is experienced as those in Scenario 1. It is worth mentioning that ICAEP continues to outperform both EP and AIS in achieving the lowest power loss. At this loading condition, the four generators require Q_{g2} = 32.9856 MVAR, Q_{g5} = 24.1691 MVAR, Q_{g8} = 40.3912 MVAR and Q_{g13} = 9.6455 MVAR to achieve the lowest power loss. The results for other reactive power loading can also be referred to in the same table using all the optimization techniques.

In Scenario 3, all the 5 generators in the system participate in the ORPD scheme involving generators at Buses 2, 5, 8, 11 and 13. The implementation of ORPD involving all the 5 generators managed to reduce the total power loss in the system, solved using the three optimization techniques at all reactive power loading. For instance, at Q_{d29} = 25 MVAR, EP reduces the power loss from 20.5260 MW to 20.5454 MW, while AIS reduces its value to 18.2112 MW, and the proposed ICAEP reduces its value to 12.8786 MW. Similar observation is experienced as those in Scenario 1 and Scenario 2. It is worth mentioning that ICAEP continues to outperform both EP and AIS in achieving the lowest power loss. At this loading condition, the five generators require Q_{g2} = 65.8791 MVAR, Q_{g5} = 24.1611 MVAR, Q_{g8} = 39.3132 MVAR, Q_{g11} = 65.7558 and Q_{g13} = 54.6455 MVAR to achieve the lowest power loss. The results for other reactive power loading can also be referred to in the same table using all the optimization techniques.

Table 4. Case 2: Power Losses (P_{Loss}) with load variations at Q_{d30}

Techniques	Before	After	Q_{g2}	Q_{g5}	Q_{g8}	Q_{g11}	Q_{g13}

		Q_{d30} (MVAR)			(MVar)	(MVar)	(MVar)	(MVar)	(MVar)
Scenario 1	EP	5	17.7038	17.6884	-	48.3293	54.7427	-	160.0028
		10	18.1091	18.0001	-	50.0893	166.0028	-	185.251
		15	18.666	18.5457	-	50.1318	54.2563	-	164.6007
		20	19.5484	19.3867	-	80.4876	62.2606	-	103.8897
		25	20.9265	20.6551	-	64.1823	91.236	-	67.8687
	AIS	5	17.7038	15.5417	-	52.1122	77.431	-	12.0263
		10	18.1091	16.2417	-	65.2505	56.8623	-	37.5962
		15	18.666	17.1432	-	69.5916	59.5892	-	28.4406
		20	19.5484	17.9686	-	79.3586	43.4418	-	54.6787
		25	20.9265	18.2343	-	35.3159	82.1194	-	41.5403
	ICAEP	5	17.7038	10.0685	-	29.2052	13.4037	-	20.0948
		10	18.1091	10.5076	-	46.7517	14.1336	-	6.8134
		15	18.666	10.3833	-	33.1665	15.2234	-	34.8008
		20	19.5484	11.5246	-	31.6429	21.7563	-	25.1042
		25	20.9265	13.9025	-	24.1691	40.3912	-	9.6455
Scenario 2	EP	5	17.7038	16.8674	67.2132	48.3293	54.7427	-	160.0028
		10	18.1091	17.265	54.2343	50.0893	50.1318	-	185.251
		15	18.666	18.0757	32.6578	23.4587	80.4876	-	164.6007
		20	19.5484	18.3867	65.4564	67.4532	64.1823	-	103.8897
		25	20.9265	19.7751	21.8798	88.5675	102.3243	-	67.8687
	AIS	5	17.7038	14.6785	79.4354	52.1122	77.431	-	12.0263
		10	18.1091	16.2534	67.0989	65.2532	56.8623	-	37.5962
		15	18.666	17.6879	166.0028	48.5546	59.5892	-	28.4406
		20	19.5484	17.1231	54.2563	65.3876	43.4418	-	54.6787
		25	20.9265	18.1934	62.2606	35.3159	82.1194	-	41.5403
	ICAEP	5	17.7038	9.6021	98.3454	29.2052	13.4037	-	20.0948
		10	18.1091	10.1564	101.3241	46.7517	14.1336	-	6.8134
		15	18.666	11.2976	87.3421	33.1665	15.2234	-	34.8008
		20	19.5484	12.1435	47.3434	31.6429	21.7563	-	25.1042
		25	20.9265	13.8034	32.9856	24.1691	40.3912	-	9.6455
Scenario 3	EP	5	17.7038	17.6884	56.4376	48.3293	54.7427	76.7878	160.0028
		10	18.1091	18.0001	88.4354	52.0893	166.0028	75.5678	185.251
		15	18.666	18.5457	82.2312	57.1318	54.2563	87.7676	164.6007
		20	19.5484	19.3867	78.3501	84.4876	62.2606	56.4565	103.8897
		25	20.9265	20.6551	71.1212	74.1823	91.236	86.5452	67.8687
	AIS	5	17.7038	15.5417	83.3332	52.1122	77.431	89.6785	12.0263
		10	18.1091	16.2417	67.3232	65.2505	56.8623	97.5654	37.5962
		15	18.666	17.1432	59.5476	69.5916	54.2123	67.6567	28.4406
		20	19.5484	17.9686	43.4148	79.3586	51.4351	54.4567	54.6787
		25	20.9265	18.2343	82.1154	35.3159	50.3243	91.0002	41.5403
	ICAEP	5	17.7038	10.0012	29.2052	67.5698	13.4037	67.5467	20.0948
		10	18.1091	10.2076	46.7517	76.7654	14.4356	37.6545	6.8134
		15	18.666	11.6453	33.1665	67.1123	15.2234	87.5676	34.8008
		20	19.5484	12.2376	32.4354	31.6429	21.7563	78.5454	25.1042
		25	20.9265	13.0032	54.8769	24.1691	40.3912	67.7558	9.6455

Case 2: Reactive Load Variation at Bus 30

In this case, three similar scenarios are considered with reactive load variation was subjected to Bus 30. Three similar scenarios using the three optimization techniques were conducted in this study.

In Scenario 1, 3 generators participate in the ORPD scheme involving generators at Buses 5, 8 and 13. In general, the implementation of ORPD involving 3 generators managed to reduce the total power loss in the system, solved using the three optimization techniques regardless of the reactive power loading. For instance, at Q_{d30} = 25 MVAR, EP reduces the power loss from 20.9265 MW to 20.6551 MW, while AIS reduces its value to 18.2343 MW, and the proposed ICAEP reduces its value to 13.9025 MW. ICAEP achieves the lowest power loss as compared to EP and AIS. This reveals the superiority of ICAEP over AIS and EP. The amount of reactive power to be dispatched by the generators are Q_{g5} = 24.1691 MVAR, Q_{g8} = 40.3912 MVAR and Q_{g13} = 9.6455 MVAR when solved using ICAEP as highlighted in the table. The results for other reactive power loading can also be referred to in the same table using all the optimization techniques.

In Scenario 2, 4 generators participate in the ORPD scheme involving generators at Buses 2, 5, 8 and 13. The implementation of ORPD involving 4 generators managed to reduce the total power loss in the system, solved using the three optimization techniques at all the reactive power loading. For instance, at Q_{d30} = 25 MVAR, EP reduces the power loss from 20.9265 MW to 19.7751 MW, while AIS reduces its value to 18.1934 MW, and the proposed ICAEP reduces its value to 13.8034 MW. ICAEP continues to outperform both EP and AIS in achieving the lowest power loss. At this loading condition, the four generators require Q_{g2} = 32.9856 MVAR, Q_{g5} = 24.1691 MVAR, Q_{g8} = 40.3912 MVAR and Q_{g13} = 9.6455 MVAR to achieve the lowest power loss. The results for other reactive power loading can also be referred to in the same table using all the optimization techniques.

In Scenario 3, all the 5 generators participation in the ORPD scheme involve generators at Buses 2, 5, 8, 11 and 13. Again ORPD scheme managed to reduce the total power loss in the system, solved using the three optimization techniques at all reactive power loading. For instance, at Q_{d30} = 25 MVAR, EP reduces the power loss from 20.9265 MW to 20.6551 MW, while AIS reduces its value to 18.2343 MW, and the proposed ICAEP reduces its value to 13.0032 MW. Similarly, ICAEP continues to outperform both EP and AIS in achieving the lowest power loss. At this loading condition, the five generators require Q_{g2} = 54.8769 MVAR, Q_{g5} = 24.1691 MVAR, Q_{g8} = 40.3912 MVAR, Q_{g11} = 65.7558 and Q_{g13} = 9.6455 MVAR to achieve the lowest power loss. The results for other reactive power loading can also be referred to in the same table using all the optimization techniques.

V. CONCLUSION

In conclusion, this paper has presented the Integrated Clonal Accelerated Evolutionary Programming (ICAEP) for reactive power management in voltage control and loss minimization in power transmission system usingORPD scheme involving the injection of reactive power to be dispatched at the generator buses. In this study, a new optimization technique, ICAEP was introduced to manage voltage control and minimize power losses in power system. The proposed technique was developed and implemented successfully as the optimization approach in determining the optimum values for sizing of the ORPD to establish voltage in the first objective and to minimize power losses in the second objective. The proposed ICAEP technique has shown to be effective in minimizing the power loss in the transmission system and improving the voltage under various load conditions at bus 29 and 30. The results show that the proposed ICAEP technique outperforms both the classical EP and classical AIS technique in terms of improving transmission system voltage as well as minimizing the power losses.

ACKNOWLEDGMENT

The authors would like to acknowledge the Research Management (RMC) UiTM Shah Alam, Selangor, Malaysia and the Ministry of Higher Education, Malaysia (MOHE) for the financial support of this research. This research is supported by MOHE under Fundamental Research Grant Scheme (FRGS) with project code: FRGS/1/2019/TK04/UITM/01/1 and 600-IRMI/FRGS 5/3 (381/2019)

REFERENCES

[1] Bhattacharyya, B., & Karmakar, N. (2020). Optimal Reactive Power Management Problem: A Solution Using Evolutionary Algorithms. IETE Technical Review, 37(5), 540-548. doi:10.1080/02564602.2019.1675541

[2] Q. H. Wu and J. T. Ma, "Power system optimal reactive power dispatch using evolutionary programming," in IEEE Transactions on Power Systems, vol. 10, no. 3, pp. 1243-1249, Aug. 1995, doi: 10.1109/59.466531.

[3] Biswas, S., Mandal, K. K., & Chakraborty, N. (2014, 11-13 Dec. 2014). Impact of modified differential evolution strategy on reactive power dispatch problem. Paper presented at the 2014 Annual IEEE India Conference (INDICON).

[4] C. Liu, N. Qin, Y. Xu and C. L. Bak, "A hybrid optimization method for reactive power and voltage control considering power loss minimization," 2015 IEEE Eindhoven PowerTech, Eindhoven, Netherlands, 2015, pp. 1-6, doi: 10.1109/PTC.2015.7232745

[5] N. R. H. Abdullah, I. Musirin and M. M. Othman, "Computational intelligence technique for solving power scheduling optimization problem," 2010 4th International Power Engineering and Optimization Conference (PEOCO), Shah Alam, Malaysia, 2010, pp. 201-206, doi: 10.1109/PEOCO.2010.5559233.

[6] S. A. Jumaat, I. Musirin, O. Muhammad Murtadha and H. Mokhlis, "PSO based technique for loss minimization considering voltage profile and cost function," 2011 5th International Power Engineering and Optimization Conference, Shah

Alam, Malaysia, 2011, pp. 36-41, doi: 10.1109/PEOCO.2011.5970456.

[7] Sahli, Z., Hamouda, A., Sayah, S., Trentesaux, D., & Bekrar, A. (2022). Efficient Hybrid Algorithm Solution for Optimal Reactive Power Flow Using the Sensitive Bus Approach. Engineering, Technology & Applied Science Research, 12(1), 8210-8216. doi:10.48084/etasr.4680

[8] Salim, N. A. B., & Maika, J. (2016, 22-25 Nov. 2016). Optimal allocation of FACTS device to improve voltage profile and power loss using evolutionary programming technique. Paper presented at the 2016 IEEE Region 10 Conference (TENCON).

[9] Jumaat, S., Musirin, P. D. I., Othman, M., & Mokhlis, H. (2012). Computational intelligence-based technique in multiple facts devices installation for power system security. Journal of Theoretical and Applied Information Technology, 31, 537.

[10] S. A. Jumaat, I. Musirin, M. M. Othman, and H. Mokhlis, “Evolutionary Particle Swarm Optimization (EPSO) based technique for multiple SVCs optimization,” in PECon 2012 - 2012 IEEE International Conference on Power and Energy, 2012.

[11] J. Zhao, L. Ju, Z. Dai, and G. Chen, “Voltage stability constrained dynamic optimal reactive power flow based on branch-bound and primal–dual interior point method,” Int. J. Electr. Power Energy Syst., vol. 73, pp. 601–607, 2015.

[12] P. Jangir, S. A. Parmar, I. N. Trivedi, and R. H. Bhesdadiya, “A novel hybrid Particle Swarm Optimizer with multi verse optimizer for global numerical optimization and Optimal Reactive Power Dispatch problem,” Eng. Sci. Technol. an Int. J., vol. 20, no. 2, pp. 570–586, 2017.

[13] Samadi H, Farrokh E. Utilization of Rock Mass Parameters for Performance Prediction of Rock TBMs Using Machine Learning Algor.

[14] S. M. Mohseni-bonab, A. Rabiee, and B. Mohammadi-ivatloo, “Voltage stability constrained multi-objective optimal reactive power dispatch under load and wind power uncertainties : A stochastic approach,” Renew. Energy, vol. 85, pp. 598–609, 2016.

[15] L. S. Titare, P. Singh, L. D. Arya, and S. C. Choube, “Optimal reactive power rescheduling based on EPSDE algorithm to enhance static voltage stability,” Int. J. Electr. Power Energy Syst., vol. 63, pp. 588–599, 2014.

[16] K. Muthukumar and S. Jayalalitha, “Electrical Power and Energy Systems Optimal placement and sizing of distributed generators and shunt capacitors for power loss minimization in radial distribution networks using hybrid heuristic search optimization technique,” Int. J. Electr. Power Energy Syst., vol. 78, pp. 299–319, 2016.

[17] D. S. Stock, F. Sala, A. Berizzi, and L. Hofmann, “Optimal control of wind farms for coordinated TSO-DSO reactive power management,” Energies, vol. 11, no. 2, 2018.

[18] M. Varadarajan and K. S. Swarup, “Network loss minimization with voltage security using differential evolution,” Electr. Power Syst. Res., vol. 78, no. 5, pp. 815–823, 2008.

[19] S. Hashemi, M. R. Aghamohammadi, and H. Sangrody, “Restoring desired voltage security margin based on demand response using load-to-source impedance ratio index and PSO,” Int. J. Electr. Power Energy Syst., vol. 96, no. September 2017, pp. 143–151, 2018.

[20] G. Saha, K. Chakraborty, and P. Das, “Voltage stability prediction on power networks using artificial neural networks,” Indones. J. Electr. Eng. Comput. Sci., vol. 10, no. 1, pp. 1–9, 2018.

[21] T. T. Nguyen, D. Ngoc Vo, N. Vu Quynh, and L. Van Dai, “Modified cuckoo search algorithm: A novel method to minimize the fuel cost,” Energies, vol. 11, no. 6, pp. 1–27, 2018.

[22] S. Sayah, “Modified differential evolution approach for practical optimal reactive power dispatch of hybrid AC–DC power systems,” Appl. Soft Comput. J., vol. 73, pp. 591–606, 2018.

[23] Gholampour A, Shahsavar J, Johari A. Probabilistic Analysis of Local Liquefaction Potential Based on Spatial Variability of SPT Data. sjis 2021; 3 (1) :21-29.

[24] Badar, A. Q. H., Umre, B. S., & Junghare, A. S. (2012). Reactive power control using dynamic Particle Swarm Optimization for real power loss minimization. International Journal of Electrical Power & Energy Systems, 41(1), 133-136. doi:https://doi.org/10.1016/j.ijepes.2012.03.030

[25] Kanata, S., Suwarno, S., Sianipar, G., & Maulidevi, N. (2019). Hybrid Time Varying Particle Swarm Optimization and Genetic Algorithm to Solve Optimal Reactive Power Dispatch Problem.

[26] H. Yapici and N. Cetinkaya, "Reduction of power loss using reactive power optimization in a real distribution system," 2015 International Symposium on Innovations in Intelligent SysTems and Applications

[27] Khanmiri, D. T., Nasiri, N., & Abedinzadeh, T. Optimal Reactive Power Dispatch Using an Improved Genetic Algorithm.

[28] Jong-Hwan, K., Hong-Kook, C., Jeong-Yul, J., & Seen-Woo, L. (1996). Identification and control of systems with friction using accelerated evolutionary programming. IEEE Control Systems Magazine, 16(4), 38-47. doi:10.1109/37.526914

[29] Jeong-Yul, J., Seon-Woo, L., Hong-Kook, C., & Jong-Hwan, K. (1996, 20-22 May 1996). Low velocity friction identification and compensation using accelerated evolutionary programming. Paper presented at the Proceedings of IEEE International Conference on Evolutionary Computation.

[30] Soldevilla, F. R. C., & Huerta, F. A. C. (2019, 3-6 Sept. 2019). Minimization of Losses in Power Systems by Reactive Power Dispatch using Particle Swarm Optimization. Paper presented at the 2019 54th International Universities Power Engineering Conference (UPEC).

[31] Sheng, G., Tu, G., & Luo, Y. (2014). Application of Artificial Intelligence Techniques in Reactive Power/Voltage Control of Power System. Electronics Science Technology and Application, 1, 5. doi:10.18686/esta.v1i1.2.