

Optimal integration of capacitor and PV in distribution network based on nomadic people optimizer

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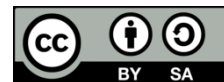
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ABSTRACT

Since the last decades, capacitor and photovoltaics (PV) are installed in distribution networks to meet the increasing in system loads. In this paper, a new application of nomadic people optimizer (NPO) algorithm is proposed to obtain the best locations and sizes of capacitor and PV alone or simultaneously in radial distribution system (RDS). Also, reactive loss sensitivity factor (QLSF) can be used for obtaining the candidate locations for installing PV and capacitor units in RDS. The efficiency of the presented technique can be applied on IEEE 69-bus and IEEE 33-bus RDS. From simulation result, installing capacitor and PV units alone in RDS decreases the total losses and increases the bus voltages. Also, simultaneous integration of PV and capacitor units give better results than integration capacitor and PV units alone in distribution network. The presented algorithm is able to explore most area of search and obtain better results than recent optimizations algorithms.

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1. INTRODUCTION

In last decades, integration of natural sources in RDS is increasing to withstand the increasing in worldwide load demand [1]-[4]. There are different types of natural sources are utilized in power grid such as hydropower, biomass, photovoltaic (PV) and wind turbine [5]-[7]. Installing PV in RDS is increased rapidly as it generates electricity from solar energy in silent and clean way [1]-[4]. Installing of capacitor in RDS is becoming more popular to reduce the reactive power supplied from substation. Therefore, integrating capacitor and PV in RDS increases the system capacity, reduces the system power loss and enhances the system voltage. QLSF are used to determine the best fifty percent of system buses for integration capacitor and PV in distribution networks [8], [9]. The presented objective function is formulated by increasing the voltage stability index and decreasing the voltage deviation and system losses as multi-objective function.

NPO algorithm is a new metaheuristic optimization algorithm to simulate the human behavior in their motion when searching for water and food [10]. This algorithm consists of several clans (swarms) and each clan consists of several families around a single leader. This algorithm depends on multi-swarm method and each swarm search for the best solution that is represented by the leader. Also, most metaheuristic optimization algorithms have faced a main problem of achieving a balance between exploration and exploitation phase, but NPO algorithm has solved this problem by its operators. These operators are families

searching, semicircular distribution, initial meeting, periodical meeting and leadership transition. The metaheuristic algorithms that are applied to determine the best sizes and locations of PV and capacitor in distribution network are genetic algorithm (GA) [11], [12], moth-flame optimization (MFO) algorithm [13], whale optimization algorithm (WOA) [14], backtracking search optimization algorithm (BSOA) [15], firefly algorithm (FFA) [16], multileader particle swarm optimization (MLPSO) algorithm [17], lightning search algorithm (LSA) [18] and flower pollination algorithm (FPA) [19].

The contributions of the paper are; i) using an efficient recent algorithm to determine the optimal planning of PV and capacitor in RDS; ii) studying the effect of integrating PV and capacitor alone in RDS; iii) studying the effect of integrating PV with capacitor in RDS; and iv) NPO algorithm is compared with efficient algorithms to measure its performance in solving optimization problem. This paper can be divided into subsections as follows: the mathematical problem is formulated in section 2, the sensitivity is explained in section 3, section 4 explains the presented algorithm, and section 5 discusses the obtained results. Section 6 displays the conclusion of the paper.

2. MATHEMATICAL PROBLEM

Figure 1 displays the representation of two buses in distribution system.

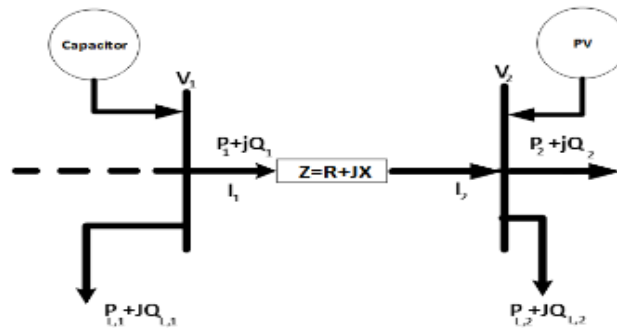


Figure 1. Representation of two buses in distribution system

In backward direction, the reactive and real power can be obtained as follows [20]:

$$P_1 = P_2 + P_{L2} + R \left(\frac{(P_2 + P_{L2})^2 + (Q_2 + Q_{L2})^2}{|V_2|^2} \right) \quad (1)$$

$$Q_1 = Q_2 + Q_{L2} + X \left(\frac{(P_2 + P_{L2})^2 + (Q_2 + Q_{L2})^2}{|V_2|^2} \right) \quad (2)$$

Then, the voltage magnitude of bus (2) can be determined in forward direction as follow:

$$V_2^2 = V_1^2 - 2(P_1 R + Q_1 X) + (R^2 + X^2) \frac{(P_1^2 + Q_1^2)}{V_1^2} \quad (3)$$

The problem formulation can be presented as multi-objective function as follows:

$$f_t = k_1 f_1 + k_2 f_2 + k_3 f_3 \quad (4)$$

$$f_1 = \sum_{m=1}^B (P_{loss}(m)) \quad (5)$$

$$f_2 = \sum_{m=1}^S (VD(m)) \quad (6)$$

$$f_3 = \frac{1}{\sum_{m=1}^S (|VSI(m)|)} \quad (7)$$

$$|k_1| + |k_2| + |k_3| = 1 \quad (8)$$

where, $VD(m)$ represents the voltage deviation at bus (m), $VSI(m)$ represents the voltage stability index at bus (m), B and S are the total number of branches and buses. k_1 , k_2 and k_3 are weighting factors that are equal to 0.5, 0.25 and 0.25, respectively.

2.1. Voltage stability index

Voltage stability index (VSI) is applied to measure the system security. Therefore, VSI can be used to measure the sensitivity of each bus to voltage collapse in RDS by (9) [21]. As long as the value of VSI for bus system is closer to 1pu, the bus voltage is closer to steady state voltage limit. Also, when the value of VSI for bus system is closer to 0pu, the bus voltage is far from steady state voltage limit. Therefore, the bus is more stable when the VSI for this bus is high and the possibilities of voltage collapse at this bus is weak. Summation of voltage stability index is the summation of VSI for system buses.

$$VSI_{(2)} = |V_1|^4 - 4(P_2 X_{1,2} - Q_2 R_{1,2})^2 - 4(P_2 X_{1,2} + Q_2 R_{1,2})|V_1|^2 \tag{9}$$

Where, $VSI_{(2)}$ represents the VSI for bus (2), $X_{1,2}$ and $R_{1,2}$ represent the reactance and the resistance among buses (1) and (2). V_1 represents the voltage at bus (1). But, Q_2 and P_2 represent the reactive and real power injection from bus (2) to RDS.

2.2. Voltage deviation

The power equality and security index can be measured using bus voltage. Therefore, any change in bus voltage affects the operation of power grid that is calculated by the voltage deviation (VD).

$$VD = (V_u - V_{ref})^2 \tag{10}$$

Where, V_{ref} represents the value that is equal to 1pu. The optimal locations and sizes of capacitor and PV can be calculated under equality and inequality constraints as shown next.

2.2.1. Equality constraints

These constraints includes power flow balance equation that can be represented as follows:

$$P_S + \sum_{m=1}^M P_{PV}(m) = \sum_{m=1}^S P_{L,m} + \sum_{m=1}^B P_{loss}(m) \tag{11}$$

$$Q_S + \sum_{m=1}^N Q_{Capacitor}(m) = \sum_{m=1}^S Q_{L,m} + \sum_{m=1}^B Q_{loss}(m) \tag{12}$$

$$P_1 = P_2 + P_{L2} + R \left(\frac{(P_2 + P_{L2})^2 + (Q_2 + Q_{L2})^2}{|V_2|^2} \right) \tag{13}$$

$$Q_1 = Q_2 + Q_{L2} + X \left(\frac{(P_2 + P_{L2})^2 + (Q_2 + Q_{L2})^2}{|V_2|^2} \right) \tag{14}$$

where, $P_{L,m}$ and P_S are the active load demand and active power injection from substation, respectively. $Q_{L,m}$ and Q_S are reactive load demand and reactive power injection from substation, respectively. M and N are the total number of PV and capacitor in RDS, respectively. $P_{PV}(m)$ and $Q_{Capacitor}(m)$ are output power of PV and capacitor at bus (m), respectively.

2.2.2. Inequality constraints

These constraints are formulated as follows:

- System voltage constraints

The bus system voltage is operating within the minimum operating voltage (V_{down}) and the maximum operating voltage (V_{up}).

$$V_{down} \leq V_c \leq V_{up} \tag{15}$$

- DER sizing limits

$$\sum_{c=1}^M P_{PV}(c) \leq (\sum_{c=1}^S P_{L,c} + \sum_{c=1}^B P_{loss}(c)) \tag{16}$$

$$P_{PV,n} \leq P_{PV} \leq P_{PV,a} \tag{17}$$

PV output operates within the minimum ($P_{PV,n}$) and maximum power $P_{PV,a}$ of PV in RDS.

- Capacitor sizing limits

$$\sum_{c=1}^N Q_{Capacitor}(c) \leq (\sum_{c=1}^S Q_{L,m} + \sum_{c=1}^B Q_{loss}(c)) \tag{18}$$

$$Q_{Capacitor,n} \leq Q_{Capacitor} \leq Q_{Capacitor,a} \quad (19)$$

The output power of capacitor is operating within the minimum ($Q_{Capacitor,n}$) and maximum power $Q_{Capacitor,a}$ of PV in RDS.

– Line capacity limits

The branches current of the system is operating under operating constraints.

$$I_m \leq I_{a,m} \quad k = 1,2,3,\dots,N.b \quad (20)$$

Where, $I_{a,m}$ is the maximum operating current through the branch (m).

2.3. Reactive loss sensitivity factor (QLSF)

QLSF measure the change in active power loss by injecting reactive power in system buses as shown in (21).

$$QLSF = \frac{\partial P_{loss(m,m+1)}}{\partial Q_{m+1}} = R_{m,m+1} \left(\frac{2Q_{m+1}}{|V_{m+1}|^2} \right) \quad (21)$$

Figure 2 and Figure 3 shows the QLSF for the presented systems, respectively. The buses with maximum QLSF values up to 50% of system buses can be defined as a candidate bus for PV and capacitor installation in RDS. The obtained candidate buses for IEEE 33-bus RDS are 6, 3, 28, 8, 29, 4, 5, 30, 9, 24, 13, 10, 27, 31, 2, 26 and 23. Also, the obtained candidate buses for IEEE 69-bus RDS are 57, 58, 7, 6, 61, 60, 10, 59, 55, 56, 12, 54, 13, 14, 15, 53, 8, 64, 49, 11, 9, 17, 48, 65, 5, 16, 21, 19, 41, 63, 68, 34, 20, 62 and 33.

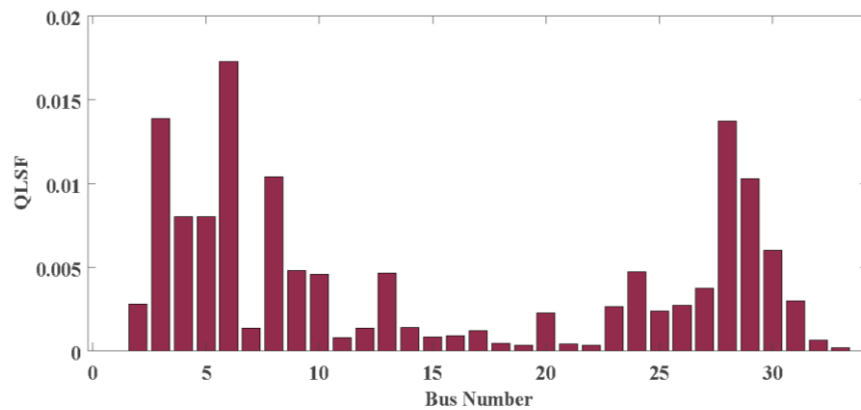


Figure 2. QLSF for IEEE 33-bus RDS

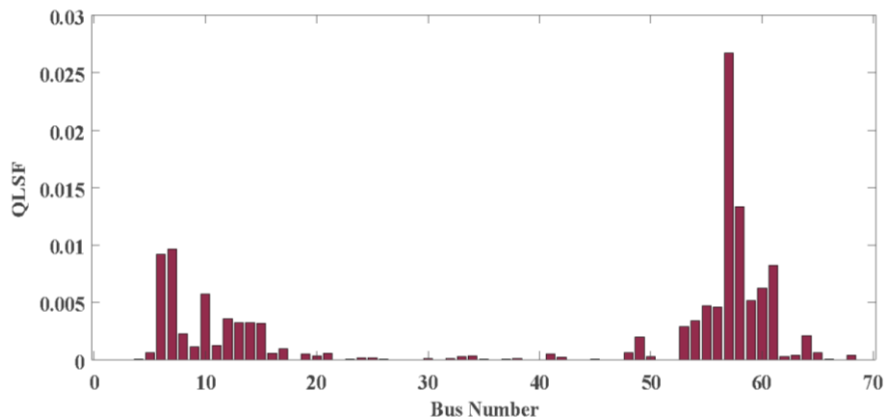


Figure 3. QLSF for IEEE 69-bus RDS

2.4. Nomadic people optimized algorithm

NPO is a recent metaheuristic algorithm that is inspired from human behavior in their motion when searching for water and food [10]. The main operators of NPO algorithm are families searching, semicircular distribution, initial meeting, periodical meeting and leadership transition. The steps of NPO algorithm to determine the optimal sizes and locations of PV and capacitor in distribution networks can be summarized as shown next.

Step 1: Enter system data, number of leaders (σ), number of families (X) and maximum iteration

Step 2: Generate initial population of leaders (clans) through initial meeting operator by (22):

$$\sigma_i = lb + rand(ub - lb) \tag{22}$$

where, lb and ub are the lower and upper value of control variables. $rand$ is a random value between (0) and (1).

Step 3: Set the position of families $X_{i,j}$ around each leader through semicircular distribution operator by (23):

$$X_{i,j} = \sigma_i \times \sqrt{R} \times |\cos \cos(\theta) \quad | \tag{23}$$

where, $X_{i,j}$ is the position of family (j) at clan (i) around a leader σ_i . R is a random value between (0) and (1) and θ is the angle between the point of family position and the point of leader position which lies between (0, 2π).

Step 4: Evaluate the fitness function for all locations of family in all swarms and obtain the best position of family $X_{i,j}^B$ in all clans or swarms.

Step 5: Set the original leader σ_i equal to $X_{i,j}^B$ as long as $X_{i,j}^B$ is better than σ_i in all clans. If σ_i is better than $X_{i,j}^B$, the families searching operator will do the next steps.

– Evaluate the average distance among all families by (24)

$$d = \frac{\sum_{i=1}^E \sqrt{(\sigma_i - X_{i,j})^2}}{E} \tag{24}$$

where, E represents the total number of families in each clan.

– Move the position of family to a new position by (25):

$$X_{new\ i,j} = X_{i,j} + (d \times (\sigma_i - X_{i,j}) \oplus Levy) \tag{25}$$

Step 6: Evaluate the fitness function for all locations of new position of families in all swarms.

Step 7: Set the position of leader σ_i equal to $X_{new\ i,j}^B$ as long as $X_{new\ i,j}^B$ is better than σ_i in all clans.

Step 8: Update the position of leaders in all clans through the periodical meeting operator by (26)

$$\sigma_{new\ i} = \sigma_i + \Delta POS \left((\sigma_i^B - \sigma_i) \times \frac{t}{T} \right) \tag{26}$$

$$\Delta POS = \varphi \left(\frac{\sqrt{\sum_{i=1}^D (\sigma_i^B - \sigma_i)^2}}{D} \right) \tag{27}$$

where, ΔPOS is the distance among the normal leader and best leader, φ refers to the direction and D is the number of dimensions for the presented optimization problem.

Step 9: Back to step 3 until the final iteration is reached.

Step 10: Obtain the best leader (σ_i^B) in all clans (positions and sizes of PV and capacitor).

3. SIMULATION RESULTS

IEEE 33-bus RDS has thirty-three buses with reactive load of 2.3 MVAR and active load of 3.715 MW and IEEE 69-bus RDS consists of sixty-nine buses with reactive load of 2694.6 KVAR and active load of 3801.5 KW as shown in Figure 4 and Figure 5 [22], [23]. The base values for these systems are 10 MVA and 12.66 KV base values. The used system constraints and algorithm parameters is introduced in Table 1.

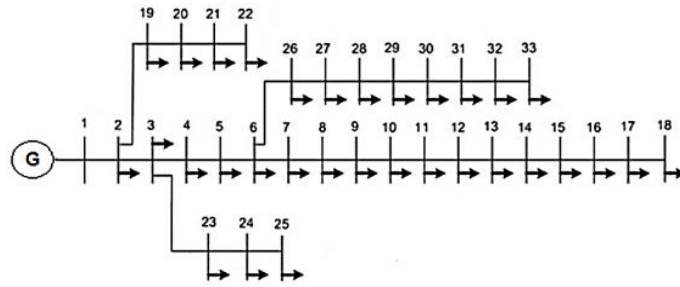


Figure 4. IEEE 33-bus RDS

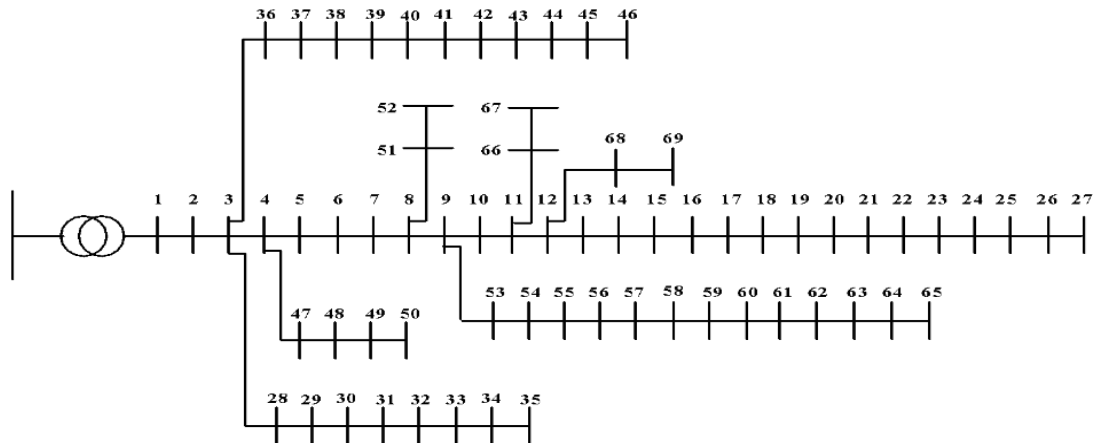


Figure 5. IEEE 69-bus RDS

Table 1. The used parameters

The used parameters	The proposed value
Number of leaders	5
Number of families	500
Maximum iteration	100
Voltage limits	$0.9 pu \leq V_i \leq 1.05 pu$
Limits of active output generation from DG	$0.3MW \leq P_{DG,i} \leq 3 MW$
Limits of reactive power generation from capacitor	$50 KVAR \leq P_{DG,i} \leq 1500 KVAR$

3.1. IEEE 33-bus RDS

Without integration PV and capacitor units in RDS, the system loss and the summation of the voltage deviation of the system are 210.972 KW, 0.1338 pu, respectively. Also, the summation of voltage stability index of the system is 25.539 with minimum voltage of 0.9038pu at bus 18. Integration of one, two and three of PV alone in distribution network decreases the system losses to 111.02 KW, 87.165 KW and 72.785 KW, respectively as shown in Table 2. Integration one and two PV alone in RDS enhance the summation of voltage stability index to 28.522 and 29.3867 and reduce the voltage deviation to 0.03771pu and 0.0169 pu, respectively. Integration of three PV alone in RDS decreases the summation of voltage deviation to 0.0151 pu, improves the summation of voltage stability index to 29.617 and enhances the minimum voltage to 0.9687 pu at bus 33. Also, integration of one, two and three capacitors alone in distribution network decreases the system losses to 151.359 KW, 141.826 KW and 138.873 KW, respectively as shown in Figure 6. The summation of voltage stability index is improved to 26.799, 27.322 and 27.244 and summation of voltage deviation is reduced to 0.0838pu, 0.0635pu and 0.0664pu by integrating one, two and three capacitors alone in RDS, respectively. Also, the minimum voltage is enhanced to 0.9165 pu, 0.9304 pu and 0.9298 pu at bus 18 by installing one, two and three capacitors alone in RDS.

From Table 2, incorporating PV with capacitor units simultaneously obtains superior results than incorporating PV alone or capacitor alone in RDS. Therefore, simultaneous integration of one, two and three PV with capacitor units in RDS reduces the system power loss to 58.443 KW, 28.578 KW and 11.740 KW, respectively. From Figure 7, the minimum bus voltage is enhanced to 0.9537 pu at bus 18, 0.9804 pu at bus 25 and 0.9921 pu at bus 8 by integrating one, two and three PV with capacitor units simultaneously in RDS,

respectively. From Figure 8, integration of one and two PV with capacitor units simultaneously in RDS improves the summation of voltage stability index to 29.805 and 31.2678, respectively. Installing three PV with capacitor units simultaneously in RDS achieves the best results as it reduces the summation of voltage deviation to 0.0006pu and enhances the summation of voltage stability index to 31.5127. The summation of voltage deviation of the system is reduced to 0.0173pu and 0.0016pu by integrating one and two PV with capacitor simultaneously in RDS, respectively. From Table 3, NPO algorithm is an efficient to obtain the best results in minimizing the system losses to 111.17 KW compared to WOA with system losses 133.503 KW for integrating one PV alone in RDS.

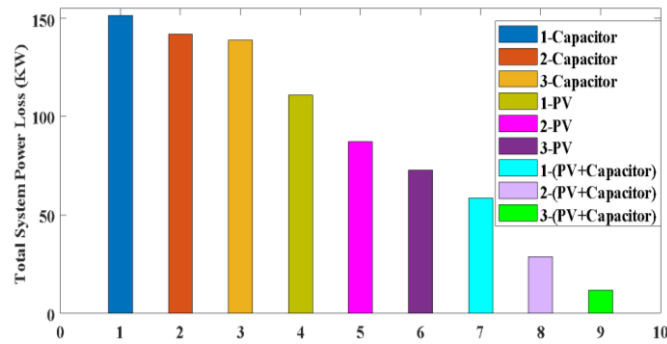


Figure 6. System losses by integrating capacitor and PV units alone or simultaneously in IEEE 33-bus RDS

Table 2. The obtained results for integrating PV alone, capacitor alone, and PV with capacitor simultaneously in IEEE 33-bus RDS

Item	Bus (PV size (KW))	Bus (capacitor size (KW))	P_{loss} (KW)	VD	VSI	Bus (minimum voltage(pu))
Without PV and Capacitor	-	-	210.972	0.133797	25.539	18(0.9038)
1-PV alone	6(2590.65)	-	111.016	0.03771	28.522	18(0.9424)
2-PV alone	13(851.83) 30(1157.7)	-	87.165	0.0169	29.3867	33(0.9685)
3-PV alone	13(802.302) 30(1053.2) 24(1091.2)	-	72.785	0.0151	29.617	33(0.9687)
1-Capacitor alone	-	30(1258) 30(1063)	151.359 141.826	0.0838 0.0635	26.799 27.322	18(0.9165) 18(0.9304)
2-Capacitor alone	-	12(466) 13(359)	138.873	0.0664	27.244	18(0.9298)
3-Capacitor alone	-	30(999) 24(367)				
1-(PV+Capacitor)	6(2531.99)	30(1256)	58.443	0.0173	29.805	18(0.9537)
2-(PV+Capacitor)	30(1139.596) 13(846.235)	30(1032) 10(468)	28.578	0.0016	31.2678	25(0.9804)
3-(PV+Capacitor)	30(1029.75) 24(1070) 13(793.98)	30(1012) 24(517) 13(373)	11.740	0.0006	31.5127	8(0.9921)

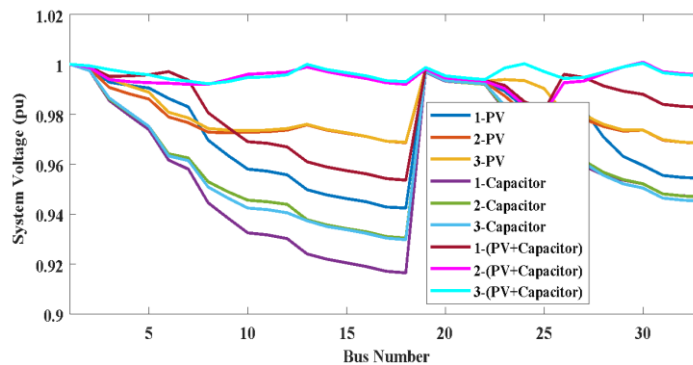


Figure 7. Bus voltages by integrating PV and capacitor units alone or simultaneously in IEEE 33-bus RDS

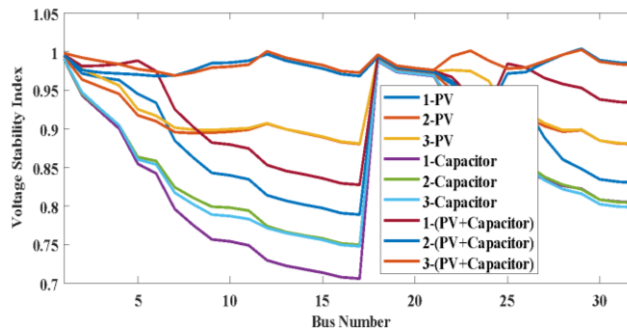


Figure 8. Voltage stability index of the system by integrating PV and capacitor units alone or simultaneously in IEEE 33-bus RDS

Table 3. The comparison results between the presented algorithm and other algorithms in IEEE 33-bus RDS

Item	NPO	Hybrid [24]	WOA [25]	SCA [26]	PSO [27]
1-PV alone	111.016	111.17	125.161	-	-
2-PV alone	87.165	87.28	-	-	-
3-PV alone	72.785	72.89	-	-	-
1-Capacitor alone	151.359	-	151.379	-	--
2-Capacitor alone	141.826	-	-	142.551	-
3-Capacitor alone	138.873	-	-	-	-
1-(PV+Capacitor)	58.443	-	-	-	59.7
2-(PV+Capacitor)	28.578	-	-	-	-
3-(PV+Capacitor)	11.740	-	-	-	-

3.2. IEEE 69-bus RDS

Without integration PV and capacitor units in RDS, the power loss is 224.975 KW with minimum voltage of 0.9092 pu at bus 65. Also, the summation of voltage deviation and voltage stability index of the system are 0.0994 pu and 61.218, respectively. From Figure 9, the system losses are reduced to 83.2224 KW, 71.6745 KW and 69.4266 KW by integrating one, two and three PV alone in RDS, respectively. The summation of voltage stability index is enhanced to 61.2184 and 64.6214 and the summation of voltage deviation is decreased to 0.0994 pu and 0.0201 pu by integrating one and two PV alone in RDS, respectively. The summation of voltage deviation is decreased to 0.0061pu, the summation of voltage stability index is improved to 66.226 and the minimum voltage is improved to 0.9789pu at bus 65 by integrating three PV alone in RDS. From Table 4, integration of one, two and three capacitors alone in distribution network decreases the system losses to 152.041 KW, 146.441 KW and 145.129 KW, respectively. Installing one, two and three capacitors alone in RDS improve the minimum voltage to 0.9307 pu, 0.9311 pu and 0.9314 pu at bus 65 as shown in Figure 10. The summation of voltage stability index is improved to 62.3427, 62.7094 and 62.8044 and summation of voltage deviation is reduced to 0.0641 pu, 0.0574 pu and 0.0559 pu by integrating one, two and three capacitors alone in RDS, respectively.

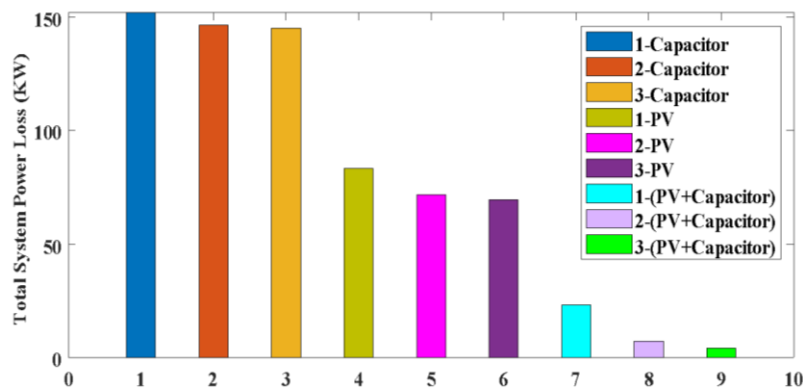


Figure 9. System losses by integrating capacitor and PV units alone or simultaneously in IEEE 69-bus RDS

From Table 4, simultaneous allocation of PV with capacitor units in RDS gives better results than other cases. The system losses are decreased to 23.169 KW, 7.201 KW and 4.253 KW by integrating one, two and three PV with capacitor units in RDS, respectively. From Figure 11, the optimal allocation of one and two PV with capacitor units simultaneously in RDS improves the summation of voltage stability index to 65.721 and 67.4824, respectively. installing one, two and three PV with capacitor units simultaneously in RDS improve the minimum voltage to 0.9725 pu at bus 27, 0.9943 pu at bus 50 and 0.9943 pu at bus 50, respectively. Installing three PV with capacitor units simultaneously in RDS achieves the best results as it reduces the summation of voltage deviation to 0.0001 pu and enhances the summation of voltage stability index to 67.7437. The summation of voltage deviation of the system is reduced to 0.0119 pu and 0.0004 pu by integrating one and two PV with capacitor simultaneously in RDS, respectively. From Table 5, NPO algorithm is an efficient to obtain the best results in minimizing the system losses to 152.041 KW compared to WOA with system losses 152.064 KW for integrating one PV alone in RDS.

Table 4. The obtained results for integrating PV alone, capacitor alone, and PV with capacitor simultaneously in IEEE 69-bus RDS

Item	Bus (PV size (KW))	Bus (capacitor size (KW))	P_{loss} (KW)	VD	VSI	Bus (minimum Voltage(pu))
Without PV and Capacitor	-	-	224.975	0.0994	61.2184	65(0.9092)
1-PV alone	61(1872.8)	-	83.2224	0.0201	64.6214	27(0.9683)
2-PV alone	61(1781.6) 17(531.56)	-	71.6745	0.0061	66.030	65(0.9789)
3-PV alone	61(1719) 17(380.581) 11(526.741)	-	69.4266	0.0052	66.2260	65(0.97898)
1-Capacitor alone	-	61(1330)	152.041	0.0641	62.3427	65(0.9307)
2-Capacitor alone	-	61(1275) 17(361)	146.441	0.0574	62.7094	65(0.9311)
3-Capacitor alone	-	61(1233) 17(252) 11(392)	145.129	0.0559	62.8044	65(0.9314)
1-(PV+Capacitor)	61(1828.519)	61(1301)	23.169	0.0119	65.7210	27(0.9725)
2-(PV+Capacitor)	61(1734.69) 17(522.36)	61(1239) 17(353)	7.201	0.0004	67.4824	50(0.9943)
3-(PV+Capacitor)	61(1674) 11(494) 17(379)	61(1195) 11(375) 21(231)	4.253	0.0001	67.7437	50(0.9943)

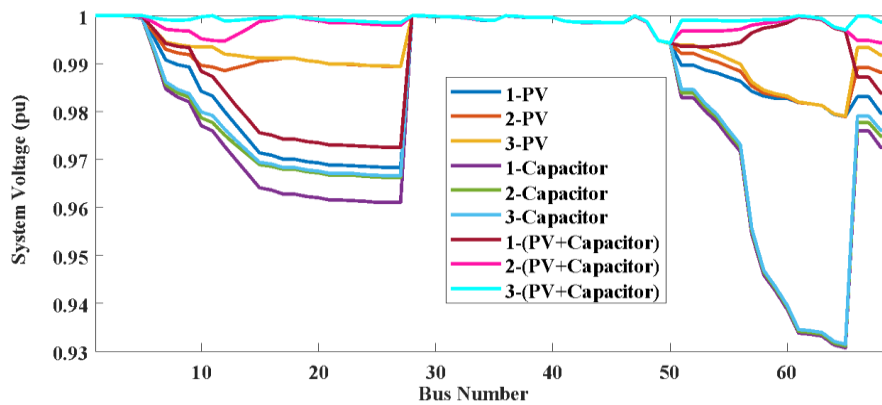


Figure 10. Bus voltages by integrating PV and capacitor units alone or simultaneously in IEEE 69-bus RDS

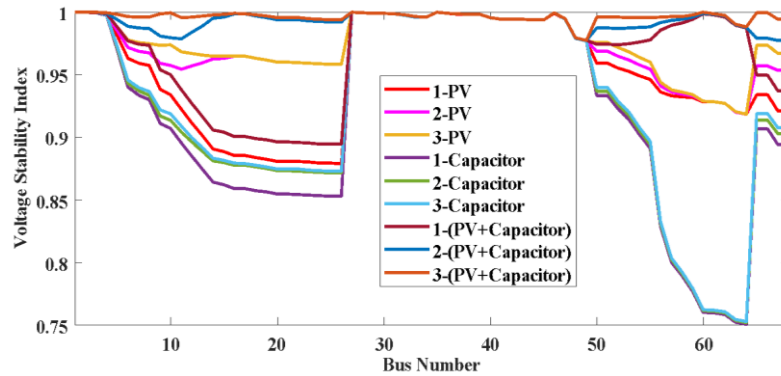


Figure 11. Voltage stability index of the system by integrating PV and capacitor units alone or simultaneously in IEEE 69-bus RDS

Table 5. The comparison results between the presented algorithm and other algorithms in IEEE 69-bus RDS

Item	NPO	MFO [8]	Hybrid [24]	WOA [25]	SCA [26]	PSO [27]
1-PV alone	83.2224	83.224	83.372	-	-	-
2-PV alone	71.6745	71.679	71.82	-	-	-
3-PV alone	69.4266	-	69.52	-	-	-
1-Capacitor alone	152.041	-	-	152.064	-	-
2-Capacitor alone	146.441	-	-	-	147.762	-
3-Capacitor alone	145.129	-	-	-	-	-
1-(PV+Capacitor)	23.169	-	-	-	-	25.9
2-(PV+Capacitor)	7.201	-	-	-	-	-
3-(PV+Capacitor)	4.253	-	-	-	-	-

4. CONCLUSION

This paper has proposed a new application of NPO algorithm to determine the best sizes and locations of PV and capacitor alone or simultaneously in distribution networks. RLSF has been applied to obtain the superior candidate buses by installing PV and capacitor units in distribution networks. From results, it is observed that integration of multiple PV and capacitor units obtains superior results than integration of single PV and capacitor. Also, integrating PV with capacitor simultaneously obtains superior results than integrating of capacitor and PV alone in RDS. NPO algorithm is able to obtain the best results when compared to than other recent algorithms. Therefore, the reduction in real power loss by installing three PV alone, capacitor alone and PV with capacitor in IEEE 33-bus RDS are 65.5%, 34.2% and 94.4%, respectively. Also, the reduction in real power loss by installing three PV alone, capacitor alone and PV with capacitor in IEEE 69-bus RDS are 69.1%, 35.5% and 98.1%, respectively. In the future work, new applications of nomadic people optimizer in solving several other complex optimization problems related to power system could be studied.

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