



Performance Improvement of a 33/11 kV, 31.5 MVA Substation Using Fixed Capacitor Banks: A PSIM-Based Comparative Study

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Abstract

The systems for transmitting and transforming electrical power are important for delivering electrical energy from generation to consumption; however, these systems typically operate at less than their potential efficiency. In this study, the capability to enhance the efficiency of a 31.5 MVA, 33/11 kV substation was investigated through the installation of a fixed 3 Mvar capacitor bank connected in a Y–Y configuration to improve the power factor of the substation. PSIM was employed as the software tool to evaluate the substation's performance at varying load conditions, namely, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% and 100% of its rated capacity. The largest improvement in power factor occurred within the load range of 10%–40%, with the power factor increasing from approximately 0.77 to 0.97. Further studies were performed to compare the effects of different capacitor bank configurations (Y, Y–Y, Y–Y–G, delta and delta + delta) at 50% load. At such load, the power factor improved from 0.645 to 0.962 when the delta configuration was used. This configuration provided the most substantial power factor correction and voltage stability amongst all the configurations. This work conducted the first comparative analysis of different capacitor configurations by using PSIM to assess the efficiency enhancement of a 3 Mvar capacitor bank in the Iraqi context. Results showed that compared with traditional Y–Y setups, the delta connection offers better power factor correction and voltage stability.

Keywords: power factor; capacitor bank; active power; reactive power; apparent power; line current; PSIM simulation

1. Introduction

By lowering the reactive demand of inductive devices, such as motors and transformers, reactive power adjustment helps mitigate issues, including poor power factor, unpredictable voltage and unnecessary energy losses. At load stations, substations and transmission lines, shunt compensation enhances efficiency and voltage regulation [1], [2]. Power factor correction (PFC), which is frequently accomplished using capacitor banks, provides reactive power of opposite polarity and is employed to reduce the phase angle between voltage and current [3]. Reactive power demands of 2.5–4 Mvar are normal for a 31.5 MVA substation that supplies residential and commercial loads. A

bank of 3 Mvar capacitors is typically chosen to maintain the power factor between 0.95 and 1 [4].

Although the advantages of capacitor banks for PFC are widely recognised, studies have confirmed that optimal placement that considers transient switching events and load unpredictability is crucial for maximising these benefits [5]. Additional research has revealed that the optimal positioning and selection of fixed-step capacitor banks via hybrid mathematical formulations can reduce annual operating costs [6].

Only a few studies have examined comparative configurations, including Y–Y, Y–Y–G, delta, and delta + delta, in Iraqi substations. The Ministry of Electricity (MOE) continues to rely largely on 3 Mvar fixed capacitor (Y–Y) configuration



installations, highlighting the importance of localised technical evaluation. This study fills this gap by conducting a simulation-based comparative analysis of a 31.5 MVA, 33/11 kV substation under realistic loading conditions with PSIM software.

Implementing fixed capacitor banks in line with MOE regulations is expected to provide multiple benefits, including the following:

- reduced active power consumption through improved efficiency, contributing to low fossil fuel use and greenhouse gas emissions;
- decreased electricity expenses by lowering demand charges;
- increased available kVA capacity in the existing supply infrastructure;
- reduced ohmic losses in distribution lines and transformers, thereby improving operational efficiency;
- enhanced system reliability and equipment lifespan by reducing electrical stress on cables and other components [7].

Capacitor banks can be configured in various forms, including delta, grounded wye (Y), ungrounded wye (Y), grounded double wye (Y–Y–G), ungrounded double wye and H configurations [8]. In this study, PSIM software was used to model the electrical behaviour of these configurations and evaluate their effects on substation performance [9]. Unlike switched capacitor banks, which can be dynamically connected or disconnected to match reactive power demand, fixed capacitor banks provide a constant level of compensation and cannot adapt to load variations [10]. Analyses indicate that the bank capacitor requirements of low-voltage distribution systems need to be improved [11].

2. Methodology

Figure 1 shows a substation's single-line diagram and capacitor bank connections (Y–Y). For the 31.5 MVA, 33/11 KV substation in this study, the fundamental formulas [12] are

$$S^2 = Q^2 + P^2, \quad \dots (1)$$

$$S = \sqrt{3} V_L I_L, \quad \dots (2)$$

$$Q = 3 q_{ph}, \quad \dots (3)$$

$$P = 3 p_{ph}, \quad \dots (4)$$

$$\cos \phi = \frac{P}{S}, \quad \dots (5)$$

$$P_{loss} = 3 I^2 R_{ph}. \quad \dots (6)$$

From the equation above, we can derive constant power and load as

$$P_{loss} = \frac{P^2 R_{ph}}{\cos^2 \phi V_L^2},$$

which means that the power loss is inversely proportional to the square of the power factor ($\cos \phi$).

$$P_{loss} = \alpha \frac{1}{(\cos \phi)^2},$$

where S, Q and P denote apparent power, reactive power and active power, respectively. V_L and I_L represent line voltage and line current, respectively. R_{ph} , q_{ph} and p_{ph} refer to resistance, reactive power and active power in the phase, respectively. The MOE requirements for the substation (33/11 KV, 31.5 MVA) state that a 3 Mvar Y–Y fixed bank of capacitors should be added to the 11 kV bus bar by the capacitor switchgear feeder to increase the power factor [13].

The magnitude of C for the capacitor bank can be calculated as

$$U = 11 \text{ kV}, \quad Q = \frac{U^2}{x_c}, \quad C = 78.8 \text{ } \mu\text{F}.$$

As shown in Figure 1, two capacitors are connected in parallel for each phase.

$$C = 2 C_{ph}, \quad \text{and} \quad C_{ph} = 39.5 \text{ } \mu\text{F}.$$

On the basis of the aforementioned relations, the substation's load parameters (31.5 MVA, 33/11 KV) were calculated, and the power factor, also known as PF or $\cos \phi$, was assumed to be 0.645, which is based on the mean value of various industries [14]. The PSIM-9.0.3 package software was used to model the circuit shown in Figure 1 to determine the effect of the capacitor bank on the substation.

PSIM 9.0.3 simulation software was employed with a fundamental frequency of 50 Hz, a time step of 50 μs and a total simulation duration of 50 ms. The system model comprised a three-phase sinusoidal voltage source, a step-down transformer rated at 33/11 kV and 31.5 MVA and fixed capacitor banks with a connected base case (Y–Y, 3 Mvar). The load was represented as an inductive element with a constant power factor of 0.645, and operating conditions were simulated in 10% increments of the substation's rated capacity, which covers the range of 10%–100%. For each load level, uncompensated

and compensated scenarios were analysed, and active power, reactive power, apparent power, source current and the power factor were recorded. Voltage and current waveforms were monitored using root mean square meters, and power quantities were calculated through PSIM's built-in measurement functions. Comparative simulations

were further conducted at 50% load to assess the performance of alternative capacitor bank configurations of 3 Mvar (Y, Y-Y, Y-Y-G, delta and delta + delta) configurations. The capacitor banks were modelled as ideal reactive elements, and no harmonic filters were incorporated at this analysis stage.

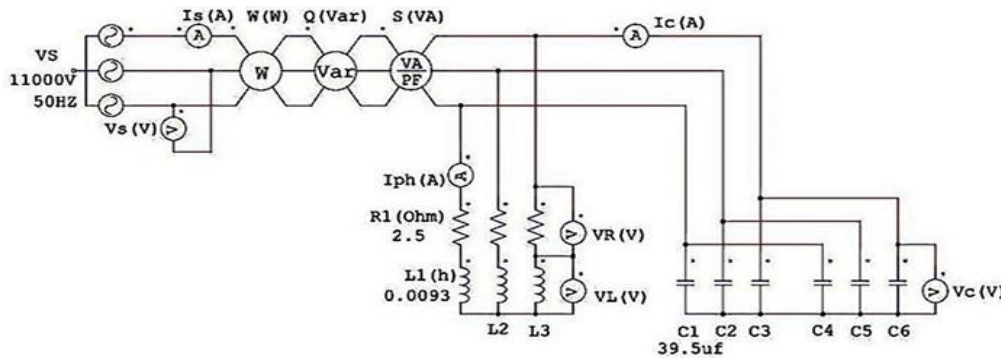


Fig. 1. Single-line diagram of the 31.5 MVA, 33/11 kV substation showing the transformer, busbars, feeder connections and capacitor bank placement.

3. Results

Two cases of fixed capacitor bank compensation were examined for the 33/11 kV, 33.5 MVA substation. The first case considered an ungrounded Y-Y capacitor bank rated at 3 Mvar, and the second case involved multiple configurations of fixed capacitor banks, each rated at 3 Mvar and connected at 50% of the substation load.

In Case 1, the key substation parameters, namely, apparent power (S), reactive power (Q), active power (P) and source current (Is), were computed before and after capacitor bank installation. S1, Q1, P1, Is1 and the power factor ($\cos \phi$) were used to represent the adjusted parameters. These calculations, which aimed to assess the influence of reactive power compensation on substation performance, were performed under various substation loading situations by using the PSIM modelling tool. Figure 2 illustrates the relevant simulation results, which show the fluctuation of these values throughout a 50 ms sample interval.

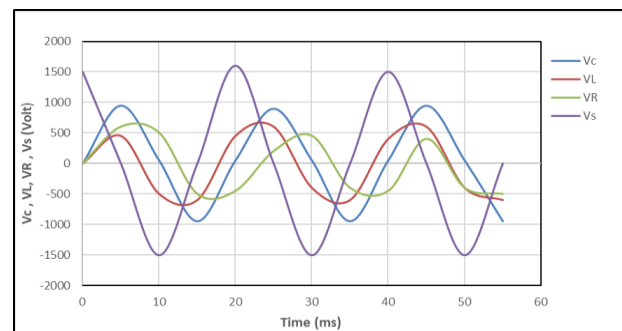
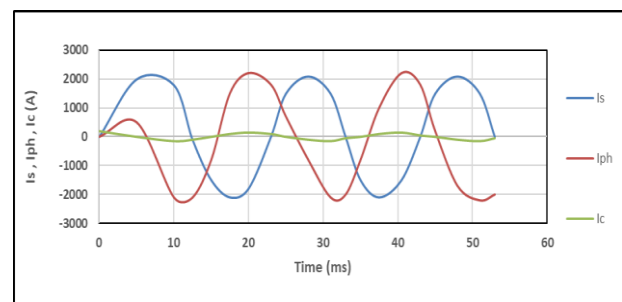
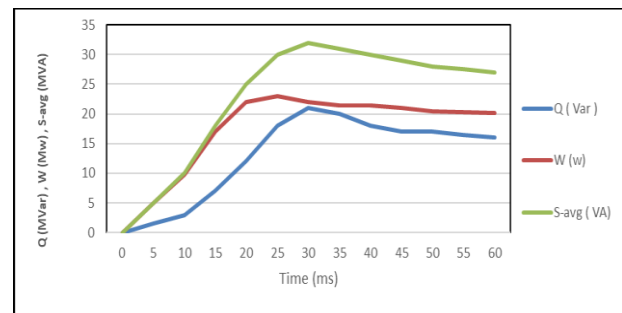
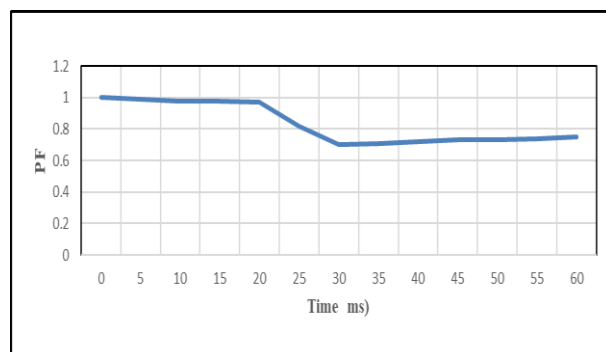


Fig. 2. PSIM simulation analysis of the 33/11 kV substation's output parameters.

The substation's characteristics determined using basic electrical formulas [12] are shown in Table 1 together with the corresponding values obtained after the construction of a fixed capacitor bank with six capacitors organised in a double-star configuration. The outcomes show a remarkable increase in the power factor and voltage stability, highlighting how well the capacitor bank works to improve system performance as a whole.

Table 1,
Measured and computed parameters of the substation before and after capacitor bank compensation.
 $\Delta S\% = 100 (S_1 - S)/S$, $\Delta P\% = 100 (P_1 - P)/P$, $\Delta Q\% = 100 (Q_1 - Q)/Q$, $\Delta I_s\% = 100 (I_{s1} - I_s)$

Load Level (%)	S (MVA)	S ₁ (MVA)	ΔS (%)	P (MW)	P ₁ (MW)	ΔP (%)	Q (Mvar)	Q ₁ (Mvar)	ΔQ (%)	I _s (A)	I _{s1} (A)	ΔI_s (%)	Cos ϕ
100	31.50	29.37	-7	20.48	20.64	1	23.94	19.08	-20	2338	2180	-7	0.695
90	28.35	26.20	-8	18.43	18.59	1	21.54	16.90	-22	2104	1946	-8	0.700
80	25.20	23.07	-8	16.38	16.32	0	19.15	14.71	-23	1870	1720	-8	0.710
70	22.05	19.92	-10	14.33	14.47	1	16.76	12.53	-25	1637	1479	-10	0.718
60	18.90	16.80	-11	12.29	12.40	1	14.36	10.38	-28	1403	1243	-11	0.729
50	15.75	13.68	-13	10.24	10.20	0	11.97	8.22	-31	1169	1020	-13	0.748
40	12.60	10.57	-16	8.19	8.26	1	9.58	6.05	-37	935	785	-16	0.773
30	9.45	7.49	-21	6.14	6.20	1	7.18	3.88	-46	701	557	-21	0.817
20	6.30	4.51	-28	4.10	4.08	0	4.79	1.72	-64	468	334	-29	0.906
10	3.15	2.10	-33	2.05	2.07	1	2.39	0.44	-118	234	155	-34	0.969

The parameters given in Table 1 are plotted against the percentage values of the substation's apparent power in Figure 3. The results show that the power factor gradually improved from 0.645 to 0.969 as the apparent power declined. Figure 4 reveals a 7%–34% reduction in apparent power (S), and Figure 5 shows a 20%–120% drop in reactive power (Q). When the load decreased from 40% to 10%, the S and Q reductions became substantial.

By contrast, Figure 6 confirms that active power (P) remained nearly constant regardless of load reduction. Figure 7 illustrates that line current (I_{s1}) decreased by 6%–34% as apparent power declined from 100% to 10%.

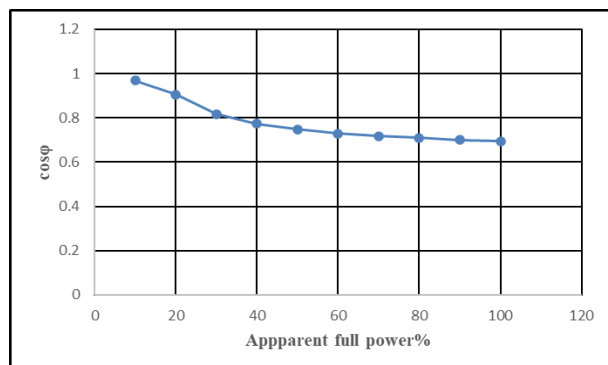


Fig. 3. Variation in the power factor (cos ϕ) with the percentage of substation apparent power (%) for the 33/11 kV, 31.5 MVA substation under the Y-Y configuration with 3 Mvar capacitor bank compensation.

All measurements came from simulations run with the PSIM program.

Afterwards, the substation's apparent power was gradually reduced from 31.5 MVA to 3.15 MVA in 10% increments, allowing the assessment of the capacitor bank's influence at various load levels. As indicated in Table 1, the power factor increased from 0.645 at full load (100%) to 0.969 at 10% load, confirming that compensation works well at low loads.

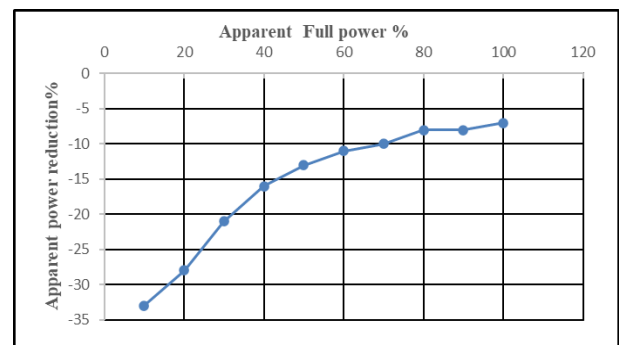


Fig. 4. Percentage reduction in apparent power with different values of apparent power (%) for the 33/11 kV, 31.5 MVA substation under the Y-Y configuration with a 3 Mvar capacitor bank.

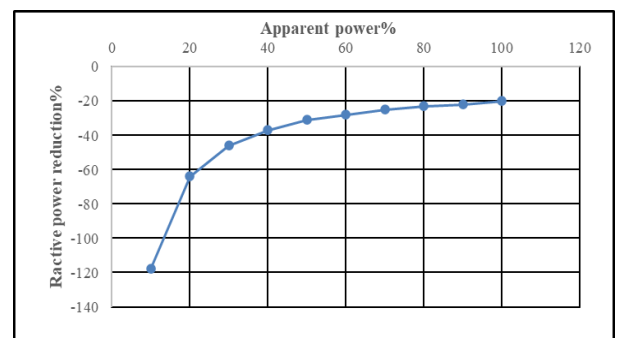


Fig. 5. Reactive power reduction (%) with various values of apparent power (%) for the 33/11 kV, 31.5 MVA substation under the Y-Y configuration with a 3 Mvar capacitor bank.

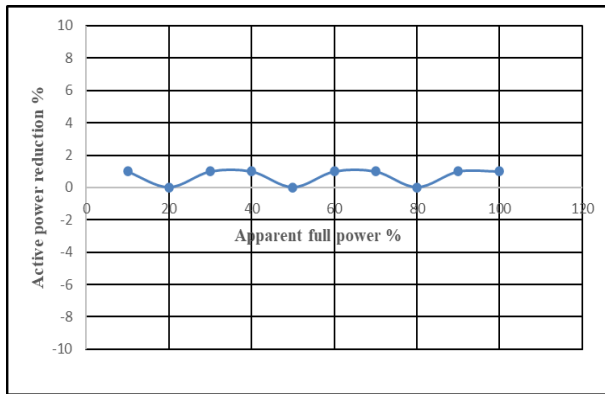


Fig. 6. Active power (P) reduction (%) with apparent power (%) in the 31.5 MVA substation under the Y–Y configuration with 3 Mvar capacitor bank installation.

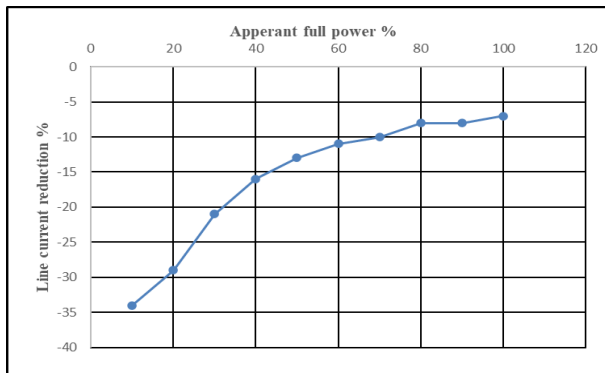


Fig. 7. Relationship between line current (A) reduction (%) and percentage of apparent power (%) for the 31.5 MVA substation under compensation by 3 Mvar Y–Y capacitor banks.

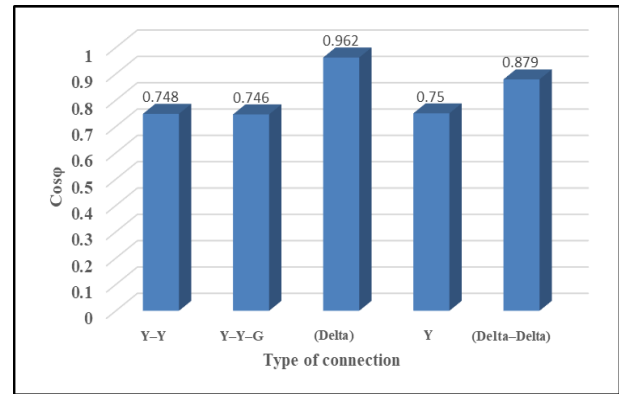


Fig. 8. Performance comparison of capacitor bank configurations (Y, Y-Y, Y-Y-G, Δ and $\Delta+\Delta$) in terms of power factor correction for 50% load of the 31.5 MVA substation.

In Case 2, different configurations of fixed capacitor banks, namely, Y–Y (ungrounded double star), Y–Y–G (grounded double star), Δ (delta connection) and delta–delta (double-delta connection), were incorporated into the substation model operating at a power factor of 0.645 and 50% load of the 31.5 MVA, 33/11 kV system. The aim of this simulation was to analyse and compare the changes in substation performance characteristics made by each capacitor bank configuration. The simulation results obtained with the PSIM program are shown in Table 2.

Table 2,

Computed and measured parameters of the substation before and after the installation of various kinds of capacitor bank compensation.

Type of Connection	S1 (MVA)	ΔS (%)	P (MW)	P1 (MW)	ΔP (%)	Q (Mvar)	Q1 (Mvar)	ΔQ (%)	Is (A)	Is1 (A)	ΔIs (%)	Cos ϕ
Y–Y	13.7	–13	10.2	10.24	0	11.97	8.22	–31	1169	1020	–13	0.748
Y–Y–G	13.7	–13	10.33	10.24	1	11.97	8.22	–31	1169	1068	–9	0.746
(Delta)	10.63	–33	10.34	10.24	1	11.97	2.64	–78	1169	789	–32	0.962
Y	13.6	–7	10.34	10.24	1	11.97	8.13	–20	1169	1011	–7	0.750
(Delta–Delta)	11.45	–27	10.34	10.24	1	11.97	0.431	–64	1169	977	–16	0.879

The delta capacitor bank arrangement produced the maximum power factor of 0.962, which exceeds that of the delta–delta configuration (0.897). The Y, Y–Y and Y–Y–G configurations reached a power factor of around 0.75, as shown in Figure 8. Figure 9 indicates that the apparent power decrease was 13%–14% for the Y-based configurations, 27% for delta–delta and 33% for delta. Meanwhile, the reduction in reactive power was about 31% for Y, Y–Y and Y–Y–G compared with

64% for delta–delta and 78% for delta. Line current decreased by 9%–14% in the Y-based connections, 16% in delta–delta, and 32% in delta, whereas active power remained unchanged across all configurations.

Figures 2–7 provide clear plots of active power, reactive power, apparent power and current before and after compensation across the full load range.

Tables 1 and 2 show quantitative comparisons that include the calculated and simulated values. For instance, at 100% load, the power factor improved only modestly (0.645 to 0.72), whereas at 10% load, the improvement was substantial (0.645 to 0.969). This result confirms that fixed capacitor banks are effective under light- to medium-loading conditions.

At 50% load, detailed simulations confirmed that the delta configuration achieved the best performance, improving the power factor from 0.645 to 0.962, compared with the Y-based configurations (Y, Y-Y and Y-Y-G) with ~0.75 and delta–delta with 0.897. In terms of current reduction, the delta, delta–delta and Y-based configurations decreased the line current by 32%, 16% and only 7%–13%, respectively.

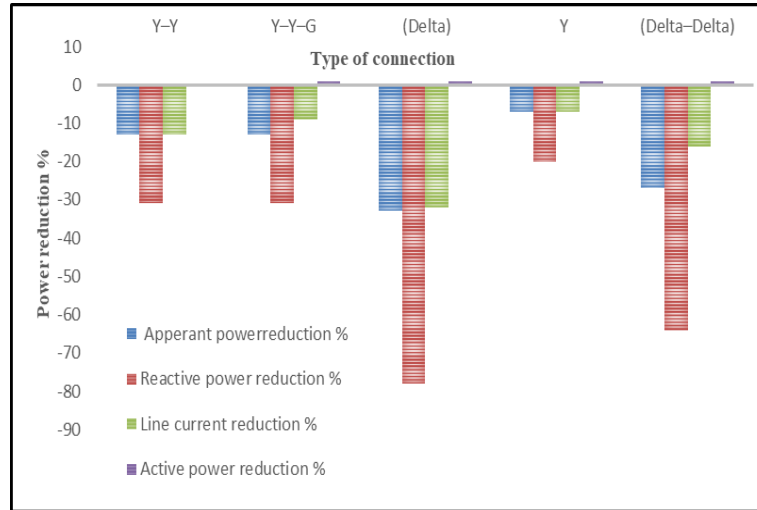


Fig. 9. Apparent power, active power, reactive power and line current reductions with various types of capacitor connections for 50% load in the 31.5 MVA substation.

**Table 3,
Comparison of this study with related research.**

Study	Method / Software	System	Capacitor Configurations	PF Before	PF After	Key Findings
This study (Hamoody et al.)	PSIM 9.0.3 simulation	31.5 MVA, 33/11 kV substation	Y, Y-Y, Y-Y-G, Δ , $\Delta+\Delta$ (3 Mvar fixed)	0.645	0.969 (Y-Y), 0.962 (Δ)	Full load sweep (10–100%); Δ configuration performs the best at 50% load with the highest PF and current reduction.
Devi & Geethanjali (2012) [2]	BFOA optimisation	Radial distribution system	Fixed capacitor sizing and placement	0.83	0.95–0.98	Bio-inspired optimisation substantially improves voltage profile and reduces losses.
Ganguly & Samajpati (2014) [3]	PSO algorithm	Distribution network	Shunt capacitor banks (fixed)	0.80–0.85	0.94–0.97	PSO-based placement improves power factor and reduces feeder losses effectively.
Ivković et al. (2024) [4]	Genetic algorithm + PowerFactory	MV distribution feeder (Gračanica)	Fixed capacitor banks with DG	0.77	0.96	DG integration enhances capacitor effectiveness and voltage stability in MV feeders

Table 3 offers a systematic comparison of the current study with some related studies that examined PFC and reactive power compensation in medium-voltage distribution substations. The comparison clarifies the degree of originality of the current work and draws attention to the methodological variations, system features, and capacitor configurations assessed throughout the literature.

4. Discussion

MOE installed a 3 Mvar fixed Y–Y ungrounded capacitor bank in the 31.5 MVA, 33/11 kV substation to improve the power factor and offset reactive power. The results indicate that the power factor ($\cos \phi$) increased from 0.645 to 0.72 at full load and to 0.96 at 10% load (Figure 3). The improvement was nonlinear, and the most notable effect occurred between 40% and 10% loading. Correspondingly, reactive power decreased by 38%–120% and line current by 15%–34% as apparent power dropped from 40% to 10% (Figures 5 and 7). Apparent power reduction rose from 7% to 13.5% when the load decreased from 100% to 50% and from 17% to 34% when the load was reduced further to 10% (Figure 4). Active power remained unaffected by capacitor installation (Figure 6). At 50% loading, the Y, Y–Y and Y–Y–G configurations improved the power factor only marginally (0.645 to 0.75), whereas delta–delta and delta achieved 0.89 and 0.96, respectively (Figure 8). The reduction in apparent power was ~13.5% for the Y-type connections, 27% for delta–delta and 33% for delta. Reactive power declined by ~31% in the Y-type connections compared with 64% in delta–delta and 78% in delta. The delta configuration provided the highest line current reduction (31%, Figure 9). Overall, the use of fixed capacitor banks was highly effective when the required compensation was moderate ($\approx 15\%$ of transformer capacity) and when the load conditions were stable, a result that is consistent with reported findings [14]. Capacitor banks can be connected to substations in two primary ways. Fixed capacitor banks are permanently connected, supplying a constant level of reactive power compensation, whereas switched capacitor banks are connected or disconnected via switches to match load requirements, thereby optimising compensation [15]. For a 31.5 MVA substation, a fixed 3 Mvar capacitor is inexpensive and easy to install, but its effectiveness decreases when the load fluctuates extremely.

Switched banks are suitable for substations with high load fluctuations because they provide superior power factor correction, dynamic compensation and voltage regulation [16]. The large reactive-to-active power ratio at light loads results in a remarkable improvement in the power factor for partial-loading situations (10%–40% of rated capacity). Under these conditions, the fixed 3 Mvar capacitor bank contributes to the necessary reactive power, resulting in a considerable adjustment. Delta-connected capacitors are superior to Y-connected banks at 50% load because of line-to-line voltage, resulting in higher reactive power per unit of capacitance, which in turn facilitates enhanced PFC, reduced line current and highly stable voltage [17,18].

The excellent performance of the delta connections has been confirmed by previous comparative research. In ETAP simulations using a fixed 3 Mvar delta bank [17], the power factor increased from 0.82 to 0.97 compared with 0.94 for a fixed 3 Mvar Y–Y configuration and 0.99 for a switched (1.5 + 1.5) Mvar delta arrangement. Similarly, MLTAP-based analysis revealed that delta provides high voltage stability and increases the power factor from 0.83 to 0.98, whereas Y reaches 0.95 [18].

The results of the present work align with these findings, showing that the delta configuration improves the power factor from 0.645 to 0.962 at 50% loading, a result that is comparable or superior to those of international results (0.82–0.97 in [17] and 0.83–0.98 in [18]). This alignment demonstrates the novelty and usefulness of the present study for medium-voltage substations in Iraq. The ideal location for capacitors to reduce power losses and enhance voltage profiles in distribution systems has been confirmed by research [19]. Notable effects on system stability and efficiency have also been provided by a study on substations operating without capacitor banks [20]. Table 3 shows that previous research focused on limited load levels or only one or two capacitor designs. By contrast, the current study conducted a detailed, in-depth comparison by examining five configurations under identical substation conditions with a 50% load range. As a result, the current analysis is highly detailed and acceptable for guiding the selection of capacitor banks for Iraqi 33/11 kV substations. Even with these benefits, harmonic distortion can be introduced or amplified by capacitor banks. According to Alotaibi et al. (2023), who showed considerable magnification of the fifth and seventh harmonics in 33/11 kV substations, fixed banks are particularly subject to harmonic amplification under partial loads, requiring the installation of detuned reactors [21]. Modern mitigation strategies include integrating detuned or tuned filters with capacitor banks or deploying active power filters (APFs) and hybrid APF–capacitor systems, which simultaneously provide reactive compensation and suppress harmonics [22,23,24,25]. Thus, whilst delta-connected banks demonstrate superior PFC and voltage stability, their practical deployment must consider harmonic distortion. For utilities such as Iraq's MOE,

incorporating detuned reactors or hybrid APF-capacitor solutions is essential to ensure compliance with IEEE 519 and IEC 61000 harmonic standards [26]. Effective mitigation planning requires an understanding of the customer's and utility's harmonic contributions on the basis of load models [27]. Tutorials also offer essential directions for the design, use and protection of shunt capacitor banks [28]. The current conclusions are further supported by simulations of automatic PFC for industrial applications [29].

5. Conclusion

The fixed 3 Mvar Y–Y capacitor bank in the 31.5 MVA, 33/11 kV medium-voltage substation that operates at constant load showed the largest amount of compensation compared with the other bank types, representing around 10%–40% of the total substation capacity. At 50% load, the fixed 3 Mvar delta capacitor bank was the most advantageous configuration for improving the power factor and voltage stability in the 31.5 MVA, 33/11 kV substation, provided that no ground connection was necessary. Therefore, capacitor banks are crucial to maximise the overall performance of an electric distribution system and ensure that economic viability and operational efficiency are achieved. This study graphically analysed different fixed capacitor bank configurations under the same operating conditions by using PSIM software. It showed the practical applications of these configurations for Iraqi 33/11 kV, 31.5 MVA substations, whereas previous studies were limited to evaluating only individual configurations. As a result, the value of the study as a decision support tool for utilities is increased, particularly when selecting between fixed delta and fixed Y–Y banks. The data indicate that delta capacitor banks (where ground standards do not apply) should be used in future system upgrades for the Iraqi power industry. For medium-voltage substations with varying loads, shunt capacitors may need to use switched capacitor banks or dynamic compensation systems [16]. Future research should examine the effects of distributed solar photovoltaic (PV) systems on reactive power management. Incorporating smart PV inverters into shunt capacitor banks allows for dynamic volt-ampere reactive control, thus enabling the inverters to absorb or deliver reactive power to stabilise voltage profiles and reduce the frequency of capacitor switching [31]. Furthermore, practical validation should be performed using PSIM simulations to verify the numerical results and assess

the actual performance of fixed capacitor bank compensation in all possible operating conditions.

Conflicts of Interest

The authors declare no conflict of interest regarding the publication of this paper.

References

- [1] M. Y. Mon, "Design and Calculation of 5 MVAR Shunt Capacitor Bank at 33 kV Bus in Distribution Substation," *Int. J. Sci. Eng. Technol. Res.*, vol. 3, no. 15, pp. 3259–3263, Jul. 2014.
<https://www.semanticscholar.org/paper/Design-and-Calculation-of-5-MVAR-Shunt-Capacitor-at-Mon/137d3af39bde73feaa75f41b6a9d159923827f22>
- [2] Matias, "Reactive Power Compensation," *High Voltage Components, ABB High Voltage Products*, p.9, Jun. 9, 2013.
<https://new.abb.com/docs/librariesprovider78/c-hile-documentos/jornadas-tecnicas-2013---presentaciones/4-jos%C3%A9-matias---reactive-power-compensation.pdf?sfvrsn=2>
- [3] A. Taye, "Design and Simulation of Automatic Power Factor Correction for Industry Application," *Int. J. Eng. Technol. Manage. Res.*, vol. 5, no. 2, Feb. 2018. DOI:10.29121/ijetmr.v5.i2.2018.142
https://www.granthaalayahpublication.org/ijetmr-ojms/index.php/ijetmr/article/view/02_IJETMR18_A01_242
- [4] J. J. Grainger and W. D. Stevenson, *Power System Analysis*. New York, NY, USA: McGraw-Hill, 1994.
https://ritwikchowdhury.files.wordpress.com/2017/12/power_system_analysis_john_grainger_1st.pdf
- [5] A. Sahib and H. Al-Baidhani, "Power Factor Improvement by Shunt Capacitor Bank at 33 kV Busbar in a Distribution Substation," in *Proc. 2022 3rd Information Technology to Enhance e-learning and Other Application (IT-ELA)*, Baghdad, Iraq, 2022, DOI: 10.1109/IT-ELA57378.2022.10107963
<https://orcid.org/0000-0002-4729-3555>
- [6] O. D. Montoya, F. D. Moya, and A. Rajagopalan, "Annual Operating Costs Minimization in Electrical Distribution Networks via the Optimal Selection and

- Location of Fixed-Step Capacitor Banks Using a Hybrid Mathematical Formulation,” *Mathematics*, vol. 10, no. 9, 2022.
<https://www.mdpi.com/2227-7390/10/9/1600>
- [7] A. Chandra and T. Agarwal, “Capacitor Bank Designing for Power Factor Improvement,” *Int. J. Emerg. Technol. Adv. Eng.*, vol. 4, no. 8, Aug. 2014.
https://www.academia.edu/33380279/Capacitor_Bank_Designing_for_Power_Factor_Improvement
- [8] P. Mysore, “Tutorial on Shunt Capacitor Banks Design, Application and Protection Considerations,” *HDR, Minnesota Power Syst. Conf.*, p. 47, Nov. 12, 2015.
<https://studylib.net/doc/18031312/shunt-capacitor-banks-design--application-and-protection>
- [9] A. Jeraldine Viji and M. Sudhakaran, “Three Phase Active Shunt Power Filter with Simple Control in PSIM Simulation,” *Journal of Information Engineering and Applications*, vol. 5, no. 2, pp. 1–7, 2015.
<https://www.iiste.org/Journals/index.php/JIEA/article/view/20338>
- [10] A. Mahmood, “Evaluation of Centralized Reactive Power Compensation in Medium Voltage Substations Using Fixed Capacitor Banks,” *M.Sc. thesis, Univ. of Baghdad*, 2023.
- [11] S. Ivković, A. Bosović, and M. Musić, “Optimal capacitor placement in real distribution network with reactive power support of distributed generation,” *B&H Electrical Engineering*, vol. 18, no. 1, pp. 12–23, Jun. 2024, doi: 10.2478/bhee-2024-0002.
<https://doi.org/10.2478/bhee-2024-0002>
- [12] B. L. Theraja and A. L. Theraja, *A Textbook of Electrical Technology*, vol. 1, S. Chand, pp. 672, 679, 2005.
- [13] Ministry of Electricity, General Directorate Basrah Electricity Distribution Substation Division, “Technical Specification of 33/11 kV Substation 2×31.5 MVA,” *Specification No. D-01B*, p. 16, 2001–2010.
- [14] SARI/Energy, “Power Factor of Various Industries,” *USAID South Asia Regional Initiative for Energy*, New Delhi, India, pp. 20–21, 2002.
<https://sari-energy.org/>
- [15] Schneider Electric, “PowerFactor Correction and Harmonic Filtering Solutions”, *MV Catalogue*, p. 15, 2010.
<https://www.scribd.com/document/177123493/Schneider-Power-Factor-Correction>
- [16] M. Y. Naqash and Z. Rashid, “PI controller based automatic power factor correction (APFC) using capacitor bank,” *Electrical, Control and Communication Engineering*, vol. 19, no. 1, pp. 40–48, 2023, DOI: 10.2478/ecce-2023-0006.
- [17] S. Ivković, A. Bosović, and M. Musić, “Optimal capacitor placement in real distribution network with reactive power support of distributed generation,” *B&H Electrical Engineering*, vol. 18, no. 1, pp. 12–23, Jun. 2024, doi: 10.2478/bhee-2024-0002.
<https://doi.org/10.2478/bhee-2024-0002>
- [18] R. Ibrahim, “Modeling and Simulation of Fixed Capacitor Banks in 33/11 kV Substations for Loss Reduction and Power Factor Improvement,” *M.Sc. thesis, Middle Technical University, Baghdad, Iraq*, 2022.
- [19] C. Z. Zangpo, T. Jamtsho, W. Tshering, S. Nethagani, and T. Tobgay, “Optimal capacitor placement for minimizing power losses and improving voltage profile on distribution system of Dewathang feeder,” *Zorig Melong: A Technical Journal of Science, Engineering and Technology*, vol. 8, no. 2, 2025, Doi: 10.17102/zmv8.i2.016.
<https://publication.cst.edu.bt/index.php/zm/article/view/162>
- [20] M. Ahmadi Kamarposhti, R. Ghandour, M. Abdel-Aty, M. Hafez, M. Alfiras, S. Alkhazaleh, I. Colak, and A. Solyman, “Optimizing capacitor bank placement in distribution networks using a multi-objective particle swarm optimization approach for energy efficiency and cost reduction,” *Scientific Reports*, vol. 15, Art. no. 12332, Apr. 2025, doi: 10.1038/s41598-025-96341-8.
<https://doi.org/10.1038/s41598-025-96341-8>
- [21] K. Liu et al., “Harmonic current variation characteristics of shunt capacitors based on full-phase FFT algorithm,” *Applied Mathematics and Nonlinear Sciences*, vol. 8, no. 1, pp. 2893–2910, 2023, Doi: 10.2478/amns.2023.1.00008
<https://www.researchgate.net/publication/370391735>
- [22] I. Hadzhiev, D. Malamov, I. Balabozov, and I. Yatchev,
- [23] “Analysis of higher harmonics during reactive power compensation by a capacitor bank,” in *2019 II International Conference on High Technology for Sustainable Development (HiTech)*, Sofia, Bulgaria, 2019, doi: 10.1109/HiTech48507.2019.9128122.
<https://www.researchgate.net/publication/342578006>
- [24] T. E. Atuchukwu et al., “Harmonic Mitigation and Energy Savings in 13.2 kV

- Distribution Networks Using an Active Power Filter,” *Energies*, vol. 18, no. 21, 2025. <https://doi.org/10.3390/en18215582> J. F. <https://www.researchgate.net/publication/342578006>
- [25] J. F. Mudaheranwa “Reducing of Harmonics using Active Power Filter in Electric Power System,” Conference: 2021 IEEE Southern Power Electronics Conference (SPEC) DOI:10.1109/SPEC52827.2021.9709462 <https://www.researchgate.net/publication/358648876>
- [26] IEEE Std 519-2014, IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems, IEEE, 2014. DOI. 10.1109/TIE.2008.2008771.
- [27] Ö. Gül and T. Gündoğdu, “Harmonic Contributions of Utility and Customer Based on Load Model Using Field Measurements,” *J. Power Energy Eng.*, vol. 3, pp. 11–28, 2015. DOI:10.4236/jpee.2015.35002 <https://www.researchgate.net/publication/276422133>
- [28] P. Mysore, “Tutorial on Shunt Capacitor Banks Design, Application and Protection Considerations,” HDR, Minnesota Power Syst. Conf., p. 47, Nov. 12, 2015. <https://studylib.net/doc/18031312>
- [29] A. Taye, “Design and Simulation of Automatic Power Factor Correction for Industry Application,” *Int. J. Eng. Technol. Manage. Res.*, vol. 5, no. 2, Feb. 2018. <https://doi.org/10.29121/ijetmr.v5.i2.2018.142>
- [30] Y. Fan, Y. Yang, and F. Wu, “Coordinated Reactive Power–Voltage Control in Distribution Networks with High-Penetration Photovoltaic Systems Using Adaptive Feature Mode Decomposition,”
- [31] *Energies*, vol. 18, no. 11, p. 2866, May 2025. DOI:10.3390/en18112866. <https://www.mdpi.com/19961073/18/11/2866>
- [32] Y. Fan, Y. Yang, and F. Wu, “Coordinated Reactive Power–Voltage Control in Distribution Networks with High-Penetration Photovoltaic Systems Using Adaptive Feature Mode Decomposition,”
- [33] *Energies*, vol. 18, no. 11, p. 2866, May 2025. DOI: 10.3390/en18112866. <https://www.mdpi.com/1996-1073/18/11/2866>

تحسين أداء محطة ثانوية ١١/٣٣ كيلو فولت، ٣١,٥ ميجا فولت أمبير باستخدام مجموعات مكثفات ثابتة: دراسة مقارنة قائمة على PSIM

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المستخلص

تُعد أنظمة نقل وتحويل الطاقة الكهربائية عنصراً أساسياً في إيصال الطاقة من التوليد إلى الاستهلاك، لكنها لا تعمل دائماً بالكفاءة المطلوبة. تتناول هذه الدراسة تقييم أداء محطة فرعية بسعة 31.5 MVA وبجهد ١١/ ٣٣ kV عند إضافة مجموعة مكثفات ثابتة بسعة ٣ Mvar موصولة على شكل Y-Y لتحسين معامل القدرة. تم استخدام برنامج PSIM لتحليل الأداء عند نسب تحميل مختلفة تتراوح بين ١٠ % و ١٠٠ % من السعة الكاملة للمحطة. وأظهرت النتائج أن تأثير التعويض يكون أكثر وضوحاً عند مستويات التحميل المنخفضة (من ١٠ % إلى ٤٠ %) حيث ارتفع معامل القدرة من ٠,٧٧ إلى ٠,٩٧. كما أُجري تحليل أكثر تفصيلاً عند ٥٠ % من الحمل لدراسة تأثير تكوينات مختلفة لبنوك المكثفات مثل (Y-Y، Y-Y، Y-Y-G، Δ+Δ، Δ) وأوضحت النتائج أن توصيل دلتا (Δ) حسّن معامل القدرة من ٠,٦٤٥ إلى ٠,٩٦٢ عند ٥٠ % من الحمل، وهو ما يوفر تحسناً أفضل لمعامل القدرة مقارنةً ببقية التوصيلات. تميزت هذه الدراسة أيضاً بكونها أول تقييم مقارنة لأداء عدة تكوينات لمكثفات ثابتة في محطة ٣١,٥ MVA، ٣٣/١١ kV باستخدام برنامج PSIM ضمن بيئة الشبكات العراقية، حيث أظهرت النتائج أن التوصيل Δ يحقق أفضل استقرار للجهد وتحسناً أكبر لمعامل القدرة مقارنةً بالتوصيل التقليدي (Y-Y).