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An approach for voltage drop improvement in 22 kV PEA distribution system based on high voltage capacitor placement

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Abstract

The distribution system has been constantly expanded with rising load demand due to population and economic growth. The result is a distribution line facing a voltage drop issue voltage drop, which results from increasing interconnected load and the distance from the substation. To mitigate this issue, this paper proposed an approach to improve the voltage level on the distribution line using a high-voltage capacitor bank. The system under study is modeled after the Provincial Electricity Authority (PEA) 22-kV distribution line. The placement of the high voltage capacitor bank will be based on the 2/3 rule technique. The PSCAD/EMTDC has been used to simulate the characteristics of the case study distribution system and evaluate the performance of the proposed technique in comparison with the PEA voltage regulation standard. The result has demonstrated the ability to use the proposed high voltage capacitor bank placement technique to improve voltage levels in the distribution system.

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Keywords: High voltage capacitor; Distribution system; Voltage improvement

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1. Introduction

In the recent decade, the demand for electricity supply in Thailand has continually increased, which results from continuous growth in population and economic urbanization, shifting to industry electricity is one of the infrastructures to drive all business sectors. This result in raising in the interconnected load on both transmission and distribution that may be harder to keep up. The everchanging load characteristic on the customer side results

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in the fluctuation in voltage profile across the distribution line that it is interconnected with. If the voltage drop by a significant margin, it can impact electrical equipment operation and may lead to permanent damage. Thus, the utility needs to address the voltage drop issue, especially in the distribution line that is directly connected to the customer to ensure the reliability of the overall system and reinforce user satisfaction.

The HV Capacitors are one of the most widely utilized distribution primary feeders, which provide additional benefits such as power loss reduction, reactive power compensation, and voltage profile improvement [1,2]. Owing more advantages to saving the economy than other devices. Thus, the voltage drop improvements are variously applied with the HV capacitor's techniques on distribution primary feeders [3,4]. In [5] the optimal HV capacitor placement on the primary feeder was applied to the 1-(1/2) distance between the load to a substation for improving the power loss. In [6], have been proposed the optimal capacitor placements technique which is utilized the 2/3 rule technique on the primary feeder [7]. By the way, these techniques have been developed for voltage drop improvement in distribution systems [8]. Considering, the voltage drop improvement by HV capacitor installation which technique was first introduced by Grainger/Lee [9,10] to comply with the 1/2 and 2/3 as simply technique to correct the position of capacitor in uncertainly loads situation. To install by covering both the fixed and switched HV capacitor along the primary feeder in the variant loads.

The goal of this research is to improve the voltage drop on the distribution system by using 2/3 techniques for HV capacitor device placement along the distribution primary feeder. The PEA standard for the voltage profile on the distribution system has been used as a reference. Additionally, the PSCAD/EMTDC program was used for simulation to determine the sizing and placement position of the HV capacitor on the distribution system, which results in an improvement in voltage drop on the system. In addition, the PEA recommends the HV capacitor sizing of 1.5 Mvar per set for placement belonging to the system, which is a regular type that is widely used in the PEA system [11,12].

2. Distribution system configuration

In this research, the case study distribution system has been selected from the section of the PEA 22-kV distribution line and modeled using PSCAD software. The 43-km line connected between Sukhothai substation (STA) and Sawankhalok substation (SWA) with the nines load group connected to the line is shown in the simplified diagram in Fig. 1. The configuration of the overhead cable and detail of nine load groups including the location of the point of connection can be summarized as shown in Tables 1 and 2 respectively.

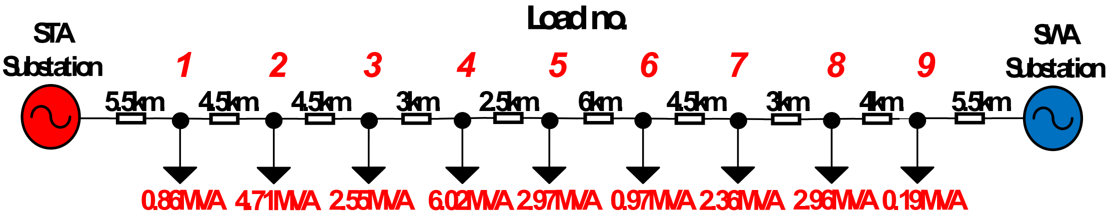


Fig. 1. Simplify single line diagram of the case study system.

Table 1. Distribution system configuration.

Parameter	Setting
Rated voltage (V_{L-L}, V_{rms})	22 kV
Boundary voltage	20.9–23.1 kV
Lean conductor	3 conductors
• SAC cable	185 sq.mm
• Outer diameter	0.00799 m.
• DC resistance	0.164 Ω
Distribution line length	43 km
Total Loads	9 Loads
PF loads	0.95

Table 2. Detail of connected load in the distribution system.

Load No.	Distance (STA – Load) (km)	Apparatus power (MVA)	PF.
1	5.5	0.86	0.95
2	10	4.71	0.95
3	14.5	2.55	0.95
4	17.5	6.02	0.95
5	20	2.97	0.95
6	26	0.97	0.95
7	30.5	2.36	0.95
8	33.5	2.96	0.95
9	37.5	0.19	0.95
		23.59 MVA	

3. 2/3 Rule technique

The 2/3 rule technique consists of the following 2 steps;

(1) to determine the sizing calculation which is HV capacitor to apply n capacitors on the feeder. The HV capacitor sizing is calculated by 2/(2n + 1) of the circuit var requirements. Meanwhile, n is the total HV capacitor for placing.

(2) the HV capacitor position is calculated by 2n/(2n + 1) of the total distance.

For Instance, the distance of the 1st HV capacitor is (2(1))/(2n + 1) of the total length between the load and the substation. The 2nd HV capacitor installation intervals of (2(2))/(2n + 1) of the total line length. The total var supplied by the capacitors is 2n/(2n + 1).

For example, when applying three HV capacitors each capacitor sizing is calculated by 2n/(2n + 1), and then 2/7 of the total vars system. On another hand, the locate placement is calculated by 2n/(2n + 1). Therefore, the distances of three HV capacitors installation will be placed at 2/7, 4/7, and 6/7 of the line length from the substation as shown in Fig. 2.

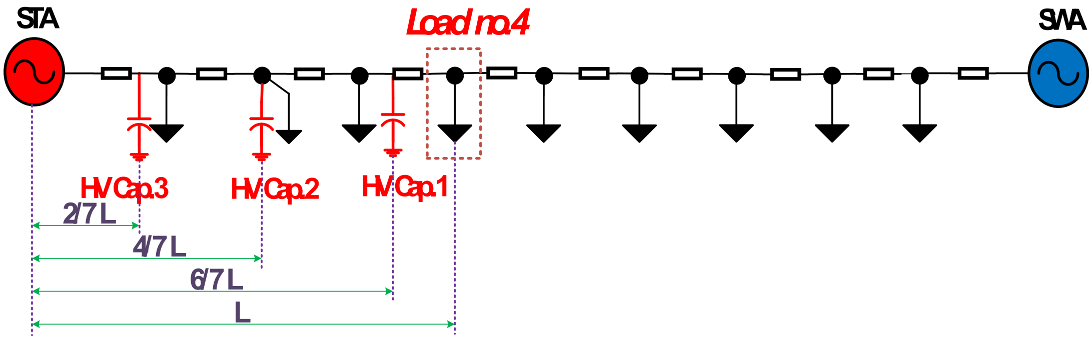


Fig. 2. Shows typical HV capacitors placements using 2/3 rule.

4. Simulation result

In this simulation, the distribution system without capacitor installation (Base case) was simulated to observe the voltage characteristics of the substations, and loads are shown in Fig. 3. The loads located near the substations (load no. 1, 8, and 9) are within PEA voltage allowance boundary. On the other hand, loads no. 2 through 7 are lower than the PEA regulation as a result of the voltage drop in cable impedance that depends on the distance from the substation. The point that has the lowest RMS voltage is located at load no. 4, which is the largest load that connects to the distribution line. This demonstrated that the voltage drop is not only proportional to the distance from a substation but also depended on the total interconnected loads on the distribution line.

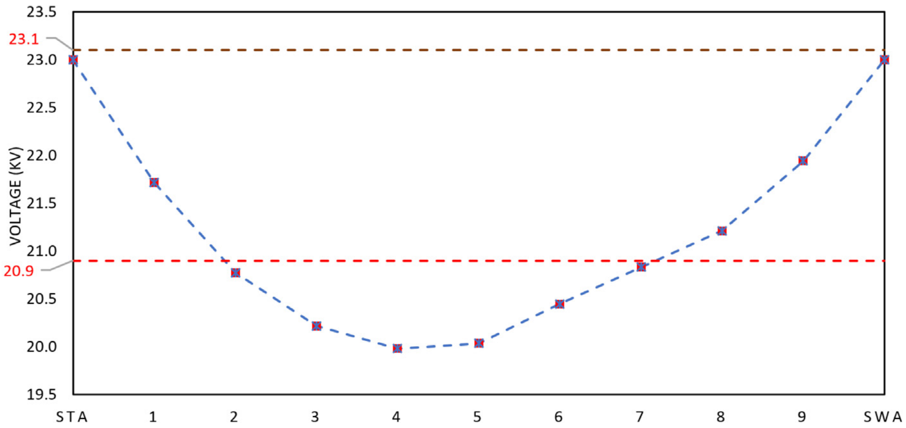


Fig. 3. Voltage profile of distribution system in the base case.

The implementation of the technique of 2/3 rule HV capacitor placement to improve voltage drop has been used in this case study distribution line. Based on the technique, the total HV capacitor size and the number position placement need to be assumed for calculation. Thus, the selected total HV capacitor size is set to be 14 Mvar and the number position placement is determined to have three positions. In the case study, load no.4 which has the highest voltage drop is taken into consideration. The HV capacitor size of each position is calculated to have 4 Mvar. In addition, the position of three HV capacitors will be calculated, which provides the positions at 5, 10, and 15 km measured from the STA substation, respectively.

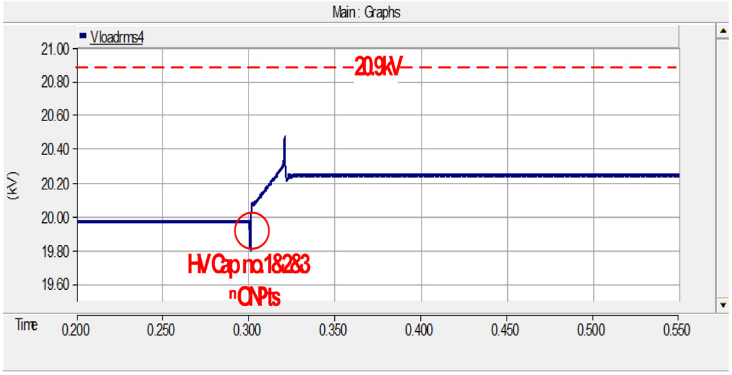
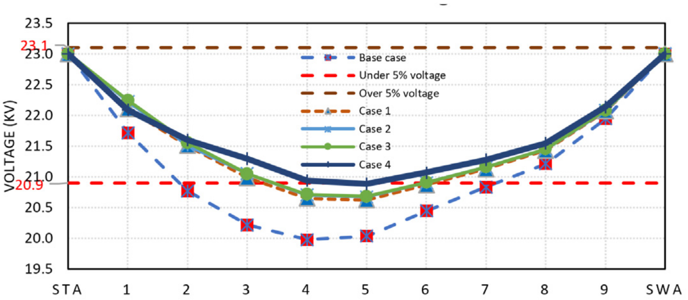


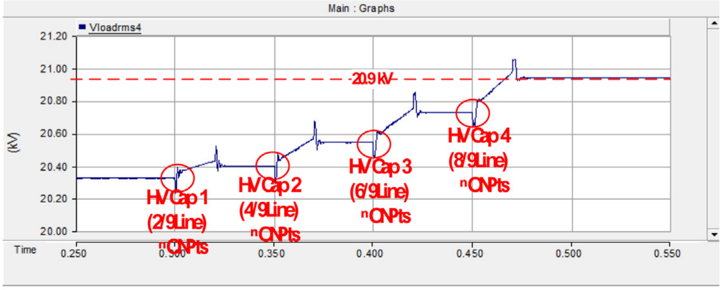
Fig. 4. Voltage Increasing using 2/3rule.

The system characteristic during switching of HV capacitor bank placement on the distribution line using the 2/3 rule approach measure from load no. 4 can be displayed as shown in Fig. 4. The HV capacitors arrangement are 1.5 Mvar × 3 positions and switched at 0.3 s, which causes a significant amount of switching transient voltage. After the system enters the steady state, it can be seen that the RMS voltage raising from 19.96 kV to 20.24 kV, or a 1.32% increase compared to the base case. This demonstrated that the installation of the capacitor bank can improve RMS voltage compare to based cases because the reactive power is energized to the system. However, the increased RMS voltage is still lower than the PEA standard. Thus, a further adjustment to the based rules is needed.

In order to improve voltage, the 2/3 rule technique has been adjusted in four different case studies. The first case study is provided by one HV capacitor, which is sized by 9.33 MVAr, while its placement is calculated based on a 2/3 distribution line measured from load no.4 or 11.7 km far away from the STA substation. The second case is provided by two HV capacitors placement, each HV capacitor sizing is 5.6 MVAr, providing total sizing of 11.2 Mvar. The two HV capacitors are placed by 2/5 line of load no.4 or 7 km and 4/5 line of load no.4 or 14 km far away from the STA substation. The Third case is HV capacitors sized 4 Mvar has been selected. Thus, there is the total sizing of HV capacitors of 12 Mvar. The first HV capacitor is installed at 2/7 line of load no.4 or 5 km far away from the STA substation, whereas the others are installed at 4/7 line of load no.4 or 10 km and 6/7 line of load no.4 or 15 km far away from the STA sub-station, respectively. Finally, in the fourth case 3 Mvar HV capacitors each have been installed on 2/9, 4/9, 6/9, and 8/9, or 3.8, 7.8, 11.7, and 15.6 km respectively. The summarized result from different cases compared to based can be summarized as shown in Table 3 and Fig. 5.



(a) 2/3 rule voltage profile



(b) Voltage increasing using 2/3 rule.

Fig. 5. Voltage profile as per 2/3 rule technique.

Table 3. RMS voltage result comparison as per 2/3 rule technique.

Description	Placement STA - load distance (km)	Base case	Case1	Case2	Case3	Case4
		HV Cap. (Mvar)	HV Cap. (Mvar)	HV Cap. (Mvar)	HV Cap. (Mvar)	HV Cap. (Mvar)
Placement and sizing of the HV capacitor	3.8	–	–	–	–	3.0
	5.0	–	–	–	4.0	–
	7.0	–	–	5.6	–	–
	7.8	–	–	–	–	3.0
	10.0	–	–	–	4.0	–
	11.7	–	9.33	–	–	3.0
	14.0	–	–	5.6	–	–
	15.0	–	–	–	4.0	–
	15.6	–	–	–	–	3.0
Total (positions)	–	–	1	2	3	4
Total installed (Mvar)	–	–	9.33	11.2	12	12
RMS voltage at load No. 4 (kV)	–	19.976141	20.648208	20.704652	20.713333	20.941049
Voltage drop improvement (%)	–	–	3.36%	3.65%	3.69%	4.82%

In case 1, the RMS voltage results of load no.2, no.3, no.4, no.5, no.6, and no.7 that is still under the PEA standard as shown in Fig. 5(a). Meanwhile, the RMS voltage load no.4 is 20.65 kV, and the percentage of improvement compared with the base case by 3.36%. Next, the two HV capacitors are investigated in case 2, the RMS voltage results measured on loads no.4 and no.5 are still less than the PEA standard. In addition, the RMS voltage result of load no.4 is improved to be 20.7 kV, which is a percentage of 3.65%. Moreover, the RMS voltage of load no.4 is increased to 20.71 kV. In case 3, the percentage of improvement is 3.69% compared to the base case as shown in Table 3. Finally, the fourth case has demonstrated the voltage profile on load no.4 is raising above PEA standard value at 20.94 kV with a percentage of improvement of 4.82%. For the transient signal, the transient voltage is divided into four steps of HV capacitor switching as shown in Fig. 5(b). It is found that the switching transient voltage in each step is lower than the switching HV capacitor in cases 1 through 3, as a result of lower HV capacitor sizing used in each step switching.

5. Conclusion

This research presents a voltage improvement technique based on the 2/3 rule in the distribution system. The case study is modeled after the section of the PEA 22-kV distribution line using PSCAD software. The simulation on the characteristic of distribution line has shown that voltage drop on distribution line with higher load interconnected is quite severe with large load no.4 can decrease voltage level on the measurement point down more than 5%. To address this issue, the HV capacitor placement based on the 2/3 rule has been proposed. The result from the implementation of the proposed HV capacitor based on 2/3 rules has demonstrated that the adjusted 2/3 rule technique can be used for voltage drop improvement on the distribution system by installing the total HV capacitor sizing of 12 Mvar for 4 positions. The RMS voltage in all of the load groups has been increased especially in load no.4, which is increased by 4.82% or at 20.94 kV level within the PEA standard allowance at 20.9 kV. Thus, the implementation of a HV capacitor bank based on 2/3 rules can improve the voltage profile by providing reactive power and raising the overall voltage level on the distribution line.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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