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CURRENT UNBALANCE REDUCTION IN LOW VOLTAGE DISTRIBUTION NETWORKS USINGAUTOMATIC PHASE BALANCING DEVICE

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ABSTRACT

This paper presents the application of an**A**utomatic **P**hase **B**alancing **D**evice **(APBD)** to reduce current unbalance in low voltage distribution networks. The proposed algorithm allowsus to calculate the unbalanced level and to conduct the automatic phase balancing device during load variations. This device was then applied to a low voltage feeder of Cau Giay district (Viet Nam). Results show that the unbalanced current is always maintained lessthan 15 %.

Keywords: automatic phase balancing device, unbalanced current, energy loss, PLC, load curve, power quality, low voltage distribution networks.

1. INTRODUCTION

During the generation, transmission, distribution and consummation of electric energy, power company and customers are very interested in power quality and reliability. Power quality is defined by the quality of frequency and voltage. The frequency is almost regulated at power plants. Meanwhile, voltage quality regulation is the main function of distribution grids because they directly supply loads. Voltage quality is represented by a set of index such as voltage deviation, voltage sag, interruption, transient overvoltage, harmonics and voltage unbalance. In this paper, the voltage unbalance is studied. There are many sources that can cause unbalance in distribution grids. One of these sources is load unbalance or current unbalance. In low distribution networks, due to major single-phase loads, this index may be not guaranteed.

Moreover, energy loss of distribution grids is also an important index, in particular in Vietnam. One of main sources of power loss in distribution networks is also current imbalance. It causesthe non-zero current flowing in the neutral conductor. As consequence, the energy loss in distribution networks increases as the unbalance level is important. Many researches suggested the evaluation method for current unbalance level and the rate of rise in line losses due to unbalance [1, 2, 3]. In addition, the neutral conductor current may cause also the serious defects for distribution networks such as overload, neutral conductor burning, voltage distorsion or distribution transformers fault [4, 5].

Within a great number of distribution transformers and low voltage networks, the increase of energy losses and the apparition of neutral conductor current become ultimately remarkable. The current unbalance reduction is thus an important objectiffor the electric utility. This fact also improves the power quality, especially in the circonstance of the distribution networks in presence of distributed generation [6, 7, 8, 9, 10]. The unbalance reduction solutions have long been studied in the literature [11, 12, 13, 14, 15]. In this work, a solution using an automatic phase balancing device (APBD)is introduced and the associated control algorithms are developed. This method was applied to a low voltage feeder of 22 kV Dich Vong substation in Cau Giay district (Ha Noi, Viet Nam).

2. CURRENT UNBALANCE REDUCTION METHOD USING AUTOMATIC PHASE BALANCING DEVICE

2.1. Methodology

Figure 1 represents a diagram of a three phase low voltage system. This system mainly supplies electrical energy to single phase loads. Although the single loads are uniformly distributed in design but the unbalance always occurs in reality because of the difference inpower consumption diffenrences.

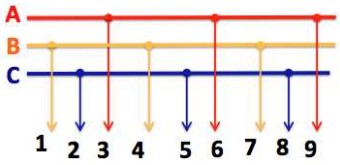


Figure 1. A typical three phase low voltage system.

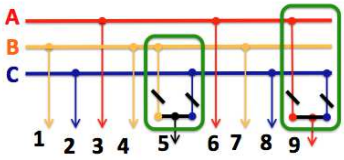


Figure 2. APBDs placement for load 5 and 9.

To reduce the unbalance level, a rephasing strategy is proposed by switching loads between phases. Since the phase current loading of the feeder is a time-varying function because of the stochastic loadcharacteristics of customers over a time period, theoptimization of phase arrangement becomes very complicated. It is thus necessary to install an automatic switching device and suitable control algorithm. Figure 2 shows an exemple of phase switching device for load 5 and 9. This type of device allows load 5 to be supplied by phase B or C, load 9 may be supplied by phase A or C. The supplingphase for load 5 and 9 is determined in order to get a possible current balance between three phases A, B and C. The number and position of APBDs are also calculated based on the load characteristic of the feeder.

2.2. Automatic phase balancing device

The principle diagram of an APBDconsisting of two switches K1 and K2 is presented in Figure 3. At any instant, there is only one closed and one opened to supply to load and to avoid short-circuit. In distribution networks, these switches are often circuit breaker. However, the alimentation will be interrupted long times during the phase rearrangement if circuit breakers are still used. Therefore, Triac is recommended during switching operation and circuit breaker will be used in normal operation.

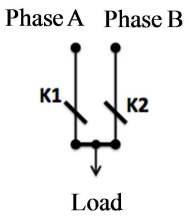


Figure 3. Principle diagram of APBD.

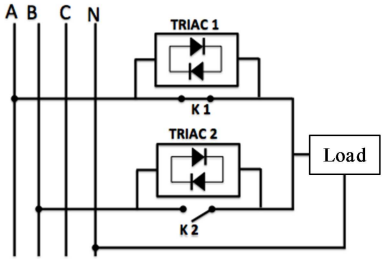


Figure 4. APBD using triac.

The principle diagram of APBD using triac is presented in Figure 4. Assuming that load is firstly supplied by phase A (switch 1 closed, switch 2 opened), two triacs do not conduct. The swithching operation of load from phase A to phase B is conducted as the following:

- Open the switch K1, Triac 2 starts conducting, load is supplied by the phase B. The total time of the switching operationis only 6 ms, customers are not affected by the outage;
- Close the switch K2, turn off the gate current pulse of triac 2, the phase rearrangement is accomplished.

This device was designed and applied to a low voltage feeder. The composition of this device is represented in Figure 5. Figure 6 shows the operating principle diagram of these APBDs on the monitoring and control WinCC software.

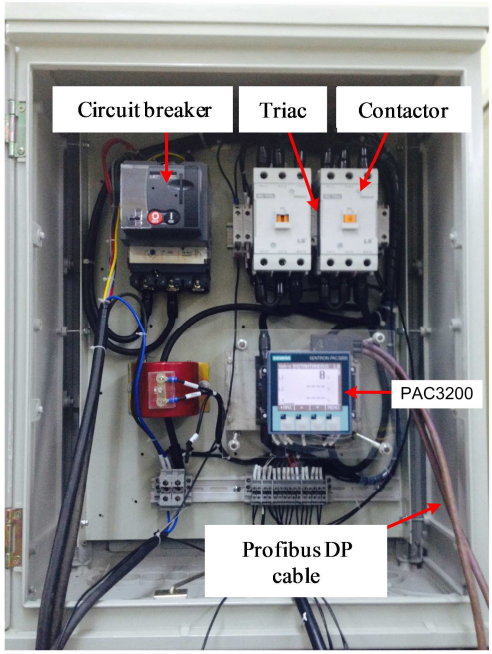


Figure 5. Composition of an APBD.

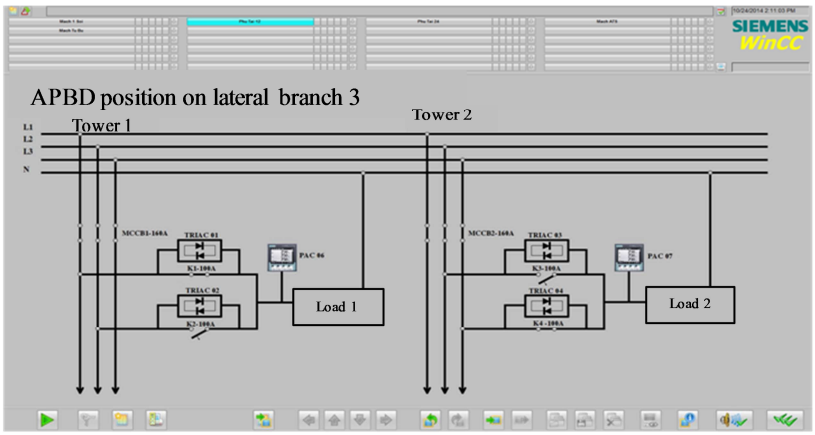


Figure 6. Operating principle diagram of APBD on the monitoring and control WinCC software.

3. 22 kV DICH VONG SUBSTATION INFRASTRUCTURE FOR AUOTMATIC PHASE BALANCE APPLICATION

22 kV Dich Vong substation of Cau Giay power company was chosen to set up a smart low voltage distribution grid. For this project, automatic phase balance possibility is one of the criterias for a smart grid. The infrastructure of low voltage network and 22 kV Dich Vong substation has been thus upgraded in order to have communication and remote control possibility (Figure 7).

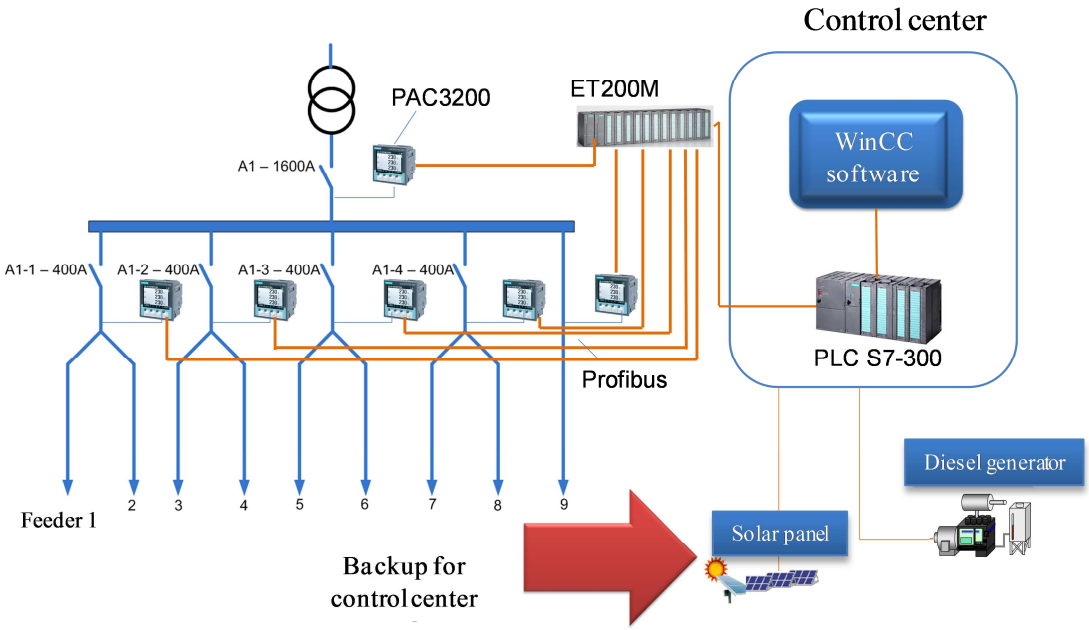


Figure 7. Low voltage network and 22 kV Dich Vong substation infrastructure.

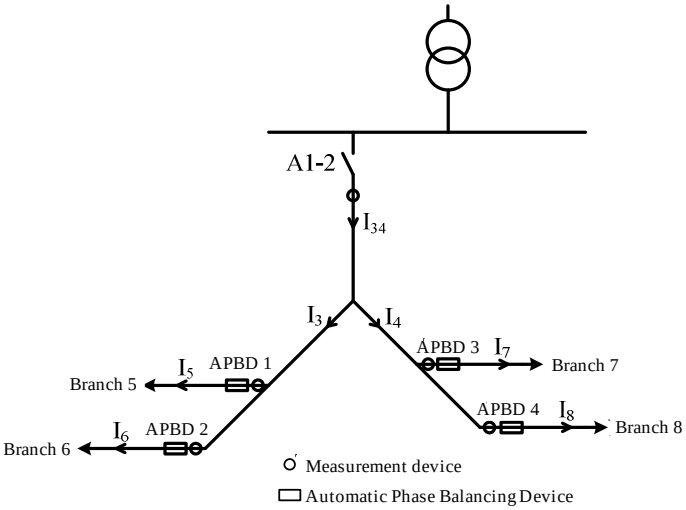
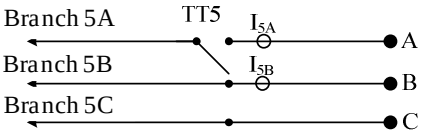


Figure 8. Placement of APBDs on the feeder 2.

Currently, the automatic phase balancing systemis installed for the feeder 2. This feeder supplies to 89 single phase loads. Four APBDs are placed in the lateral branches 3 and 4. Each device which is able to switch between two phases, is connected to 8 single phase loads. The position of these devices in the lateral branches 3 and 4 is presented in Figure 8.

APBD 1 allows load group in the lateral branch 5 to be supplied from phase A or phase B as presented in Figure 9.



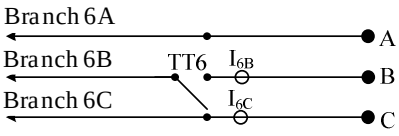
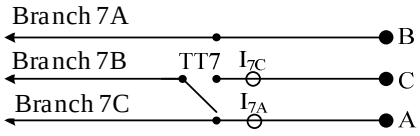


Figure 9. Alimentation posibility for load group 5. *Figure 10*. Alimentation posibility for load group 6.

APBD 2 allows load group in the lateral branch 6 to be supplied from phase B or phase C as presented in Figure 10.

APBD 3 allows load group in the lateral branch 7 to be supplied from phase C or phase A as presented in Figure 11.

APBD 4 allows load group in the lateral branch 8 to be supplied from phase A or phase B as presented in Figure 12.



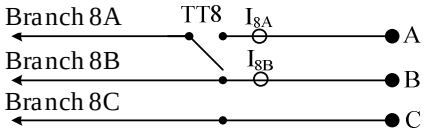


Figure 11. Alimentation posibility for load group 7. *Figure 12*. Alimentation posibility for load group 8.

The phase balance situation of the feeder 2 is determined by the balance of phase currentI_{34A}, I_{34B} and I_{34C}.These currents are measured and the unbalance level is calculated as presented in the next section. Since the unbalance level exceeds the given value, communication and control system will conduct the APBDs to switch load groups to light phase. As consequence, the unbalance between the phase currents I_{34A}, I_{34B} and I_{34C} is remained in the limited range.

4. AUTOMATIC PHASE BALANCING ALGORITHM

The input data of automatic phase balancing algorithm for feeder 2 contain:

- Phase current A of the whole feeder: I_{34A};
- Phase current B of the whole fedder: I_{34B};
- Phase current C of the whole feeder: I_{34C};
- Phase current A of the lateral branch 5: I_{5A};
- Phase current B of the lateral branch 6: I_{6B};
- Phase current C of the lateral branch 7: I_{7C};
- Phase current A of the lateral branch 8: I_{8A}.

The state of each APBD is:

- TT(5) :
  - \+ = A if load group 5 is supplied by phase A;
  - \+ = B if load group 5 is supplied by phase B.
- TT(6):
  - \+ = B if load group 6 is supplied by phase B;
  - \+ = C if load group 6 is supplied by phase C.
- TT(7):
  - \+ = A if load group 7 is supplied by phase A;
  - \+ = C if load group 7 is supplied by phase C.
- TT(8):
  - \+ = A if load group 8 is supplied by phase A;
  - \+ = B if load group 8 is supplied by phase B.

Searhing algorithm for unbalance level between phase currents I_{34A}, I_{34B}, I_{34C} is presented in Figure 13. The algorithm will determine the phases that load groups controlled by APBD are switched to since the unbalance level in current between any two phases exceeds 15 %. In this paper, we present exclusivement in detailthe algorithm corresponding to the case when I_{34A} is max and I_{34B} is min (see Figure 14).

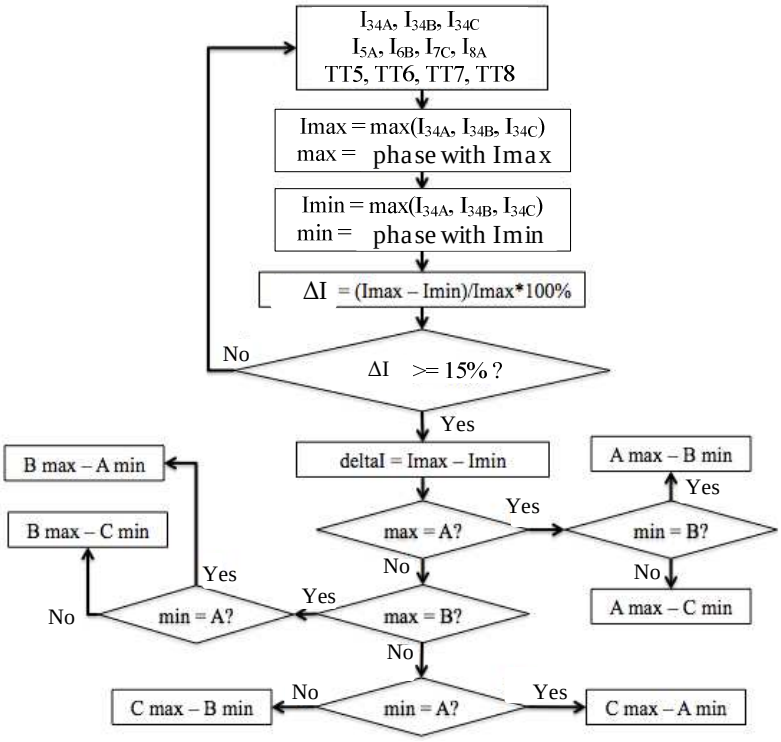


Figure 13. Phase balancing algorithm.

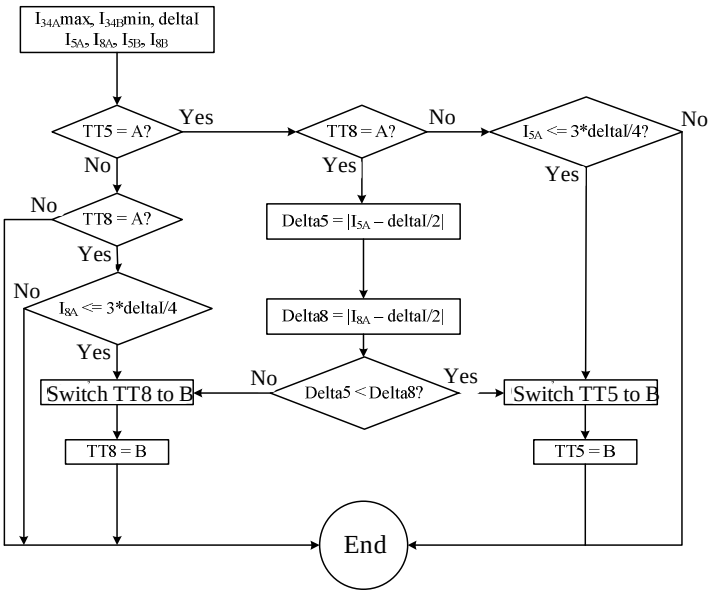


Figure 14. Control schemes since I_{34A} max and I_{34B} min.

5. RESULTS AND DISCUSSION

The measurement, communication and control system of Dich Vong substation allows us to collect the data of the phase currents of the feeder 2. The phase currents of the whole feeder I_{34A}, I_{34B}, I_{34C} on 26, 27 and 28 February 2015 are respectely presented in Figure 15, Figure 16 and Figure 17. It should be noted that these data have been collected before the operation of APBDs.

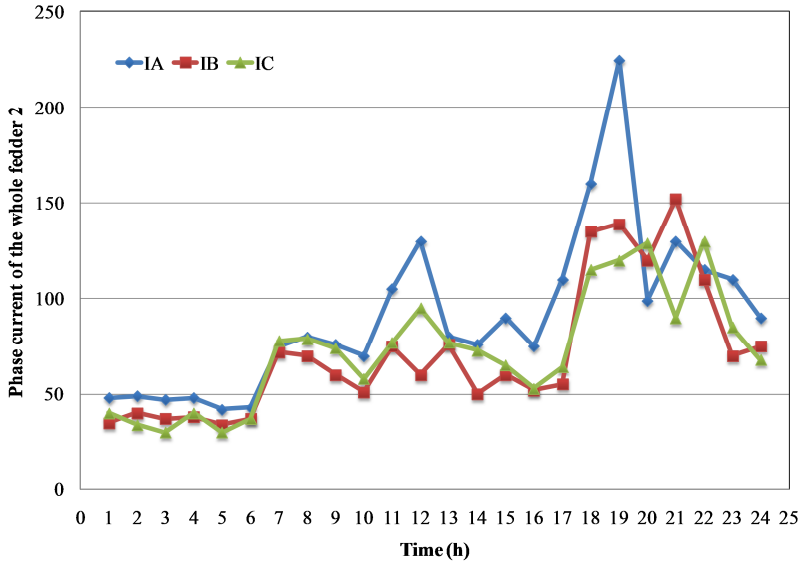


Figure 15. Phase currents I_{34A}, I_{34B}, I_{34C} recorded on 26 February 2015.

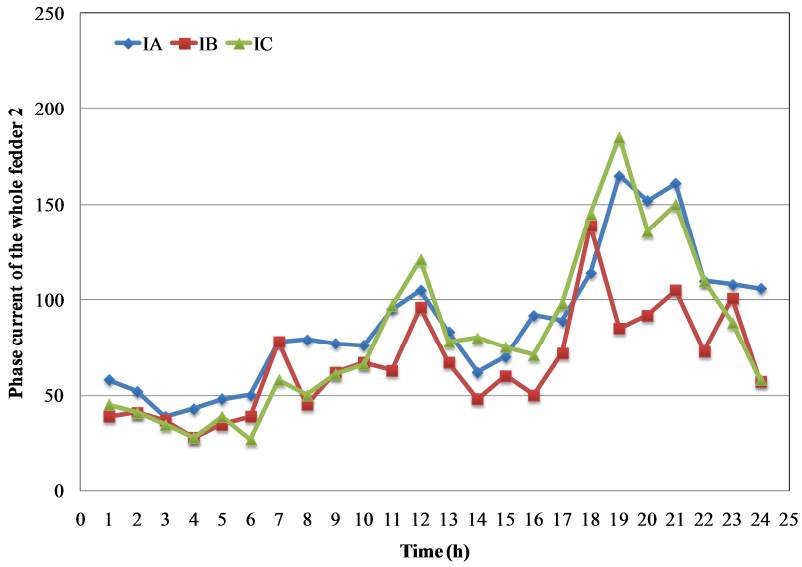


Figure 16. Phase currents I_{34A}, I_{34B}, I_{34C} recorded on 27 February 2015.

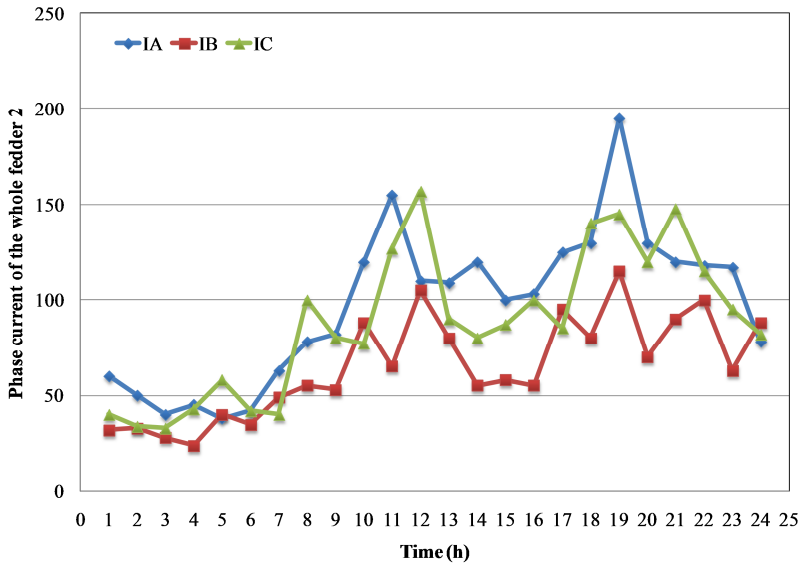


Figure 17. Phase currents I_{34A}, I_{34B}, I_{34C} recorded on 28 February 2015.

The characteristics of collected currents can be discussed as following:

- Load pattern depends on time, the peak demand occurs between 18 and 20 h;
- Unbalance level depends also on time, the maximum occurs at the same time with the peak demand (18 – 20 h);
- Load characteristic is stochastic, vary each day;
- The maximum in energy consumption is constated on phase A.

The maximum in current unbalance on 26, 27 and 28 February 2015 for the feeder 2 is reported in Table 1.

Table 1. Maximum in current unbalance on 26, 27 and 28 February 2015 for the feeder 2.

Date	Phase max	Phase min	ΔImax (%)
26	A	C	47,8
27	C	B	54,1
28	A	B	43,3

The values in Table 1 show that the current unbalance is ultimately high, exceeding the amissible limit of 15 %. The energy losses will increase if there is no compensation solution. Therefore, it is necessary to use the APBDs to avoid additional losses and power quality problem due to harmonics. We have then activated the APBDs from 28 February 2015. The phase currents of the whole feeder that have been recorded on 01 Mars 2015 are presented in Figure 18.

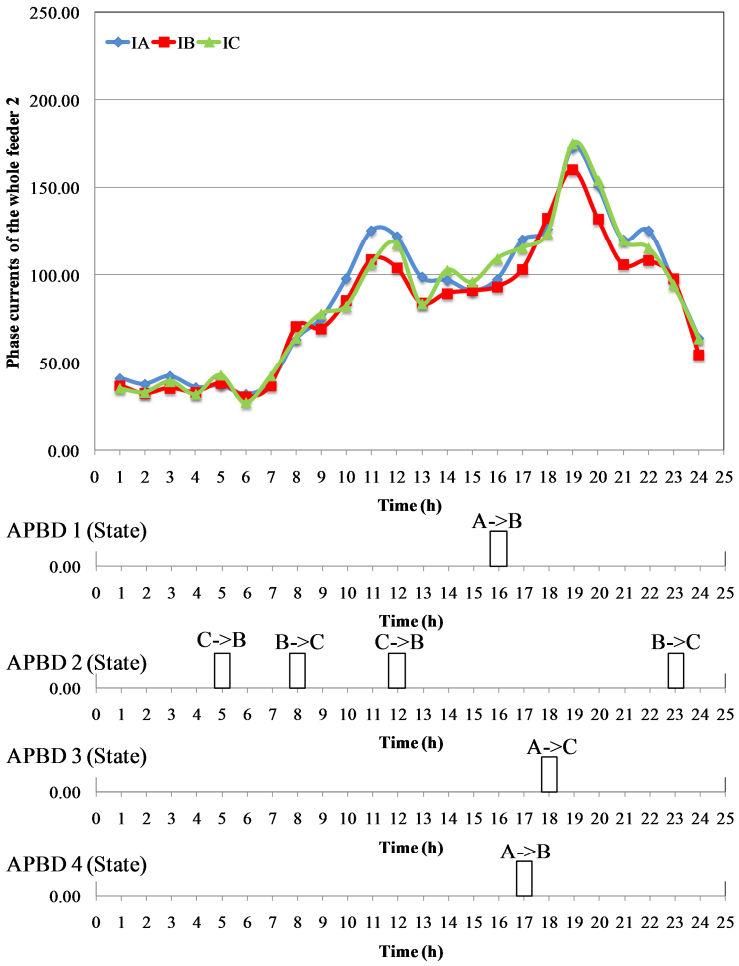


Figure 18. Phase currents of the feeder 2 recorded on 01 Mars 2015 after activating the APBDs (top). The moment of APBDs operation (bottom).

It should be noted that the phase current of the feeder 2 are relatively uniform with the operation of the APBDs. The unbalance level achives the maximum at two peaks demand (10 - 12 h and 18 – 20 h) but remains less than 15 % (Table 2).

Table 2. Unbalance level at peaks demand (noon and evening) on 01 March 2015.

Time	**ΔImax (%)**
12h	14,7
19h	8,4

Concerning the switching operation of the APBDs, we constate that the switching time of APBD 2 (which may switch load between phase B and C) is uniformly distributed. This fact is due to the balance of load between phase B and C. Otherwise, the switching time of APBD 1 (phase A to B), APBD 3 (phase A to C) and APBD 4 (phase A to B) occured on 16 h, 18 h and

17 h, respectively. During this time, most of loads were connected to phase A that raise the unbalance level. As consequence, APBD1, 3 and 4 were activated to switch loads to phase B and C.

6. CONCLUSION

Phase unbalance cause additional losses and power quality problem in low voltage distribution networks. The application of automatic phase balancing device may help to reduce unbalance level. For this fact, measurement, communication infrastructure and control schemes were built up. The experimental results obtained in low voltage distribution network of Cau Giay district have proved the efficiency of the proposed technique. The current unbalance of the feeder under study of 22 kV Dich Vong substation was remained less than 15 %. This model may be then widely applied to low voltage distribution networks in Viet Nam.

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TÓM TẮT

GIẢM ĐỘ KHÔNG ĐỐI XỨNG DÒNG ĐIỆN CỦA LƯỚI PHÂN PHỐI HẠ ÁP BẰNG ỨNG DỤNG THIẾT BỊ TỰ ĐỘNG CHUYỂN PHA

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Bài báo này giới thiệu ứng dụng thiết bị tự động chuyển pha và thuật toán cân bằng pha cho phép giảm độ không đối xứng của dòng điện, đồng thời nâng cao chất lượng điện năng của lưới điện phân phối hạ áp. Thuật toán cân bằng pha đề xuất cho phép tính toán độ không đối xứng và thực hiện chuyển phụ tải một pha khi xảy ra sự biến động phụ tải trên lưới. Ứng dụng thiết bị trên lưới điện phân phối hạ áp quận Cầu Giấy đã chứng minh mức độ mất cân bằng dòng pha luôn được giữ nhỏ hơn 15 %.

Từ khóa: thiết bị tự động cân bằng pha, độ không đối xứng, tổn thất điện năng, PLC, đồ thị phụ tải, chất lượng điện năng, lưới phân phối hạ áp.