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Application and Circuit Design of the Same-Phase Power Supply Scheme in Electrical Power Distribution Systems

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Abstract*— The same-phase power supply (SPPS) scheme is applicable to multiphase AC power distribution systems equipped with a neutral line. Technically, it uses a zero-sequence circuit to deliver power. To date, some academic papers have demonstrated and confirmed its feasibility and possible applications through computer simulation. This paper proposes some practical applications and circuit designs to apply the SPPS scheme to electrical power distribution systems. To apply the SPPS scheme, a simple changeover switch (COS) and a few optional auxiliary devices are adopted to momentarily separate a great number of large loads from the system to suspend their power supply. Hence, this scheme enables the reserved power to supply small essential loads throughout the system. In other words, the reserved power can be supplied to a large number of widely distributed small essential loads for basic quality-of-life maintenance when the power supply of the public power system is inadequate. The approaches and devices proposed in this paper can be useful for engineers in the planning and design of electrical power distribution systems to enhance their reliability and security and to reduce the impacts and damage caused by power failures or a considerable power imbalance.

***Index Terms*— changeover switch, microgrid, phase selector, same-phase power supply scheme, smart building.**

I. INTRODUCTION

On July 29, 1999, the north–south extra high voltage (EHV) power transmission line in the Taiwan power system became disconnected in an instant owing to the collapse of a 345-kV EHV power transmission tower in Lungchi. Because the power generation capacity in northern Taiwan was far lower than the power consumption, the power produced in southern Taiwan has been transported to northern Taiwan for years. At the moment that the major EHV power transmission line became disconnected, the sudden change in the system frequency and the collapse of the voltage resulted in a large-scale power failure across Taiwan. On September 21, 1999, the Chichi earthquake provided another heavy blow to the Taiwan power system and caused another serious power failure across the island. During the accident, although multiple dwelling units and commercial office buildings were ordinarily equipped with on-site emergency backup generators, their power capacities customarily failed to meet their customary power demand.

On August 31, 2003, the severe power failure in the northeast United States and the neighboring areas in Canada shocked the world. It was the most widespread power cut in the history of North America, and the number of affected people was estimated to be 50 million, with 10 million in Canada and 40 million in the United States. The losses caused by the accident were difficult evaluate. Nowadays, if the power capacity is lower than the power consumption, the system can detect it with low-frequency and low-voltage relays. Furthermore, if the system can be switched to the same-phase power supply (SPPS) mode in an instant on a large scale to wipe out nonessential loads and maintain essential loads for vital and second essential power for basic livelihood needs, an excessive deviation in the system frequency and an voltage collapse could be avoided and the possibility of a large-scale power failure and the impact and loss caused by the temporary power shortage could be significantly reduced.

In general, power companies adopt a “rolling blackout” (also referred to as rotational load shedding or feeder rotation) and “limited power alternately supplied by district” [1-3] in the case of an inadequate power balance. Limited power alternately supplied by district has a significant impact on users because its power failure period is usually longer than that of a rolling blackout. Therefore, the power company prefers a rolling blackout to reduce the impact of an inadequate power supply. However, this measure also has a significant impact on the quality of life of the affected users and can even endanger the lives of some patients.

In the SPPS scheme, a zero-sequence circuit is used for the power supply [4], which enables the suspension of the power supply to some large loads and a continuous power supply to others. By applying the SPPS scheme, loads are classified and grouped as essential and nonessential. In the SPPS scheme, a

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simple changeover switch (COS) and a few optional auxiliary devices are adopted to momentarily separate a great number of large loads from the system to suspend their power supply. The scheme enables reserved power to supply small essential loads throughout the system during the emergency period. In other words, power can be supplied to a large number of widely distributed small essential loads for basic quality-of-life maintenance when the power supply of the bulk power system is inadequate.

The approaches and devices proposed in this paper can be useful for engineers in the planning and design of electrical power distribution systems to enhance their reliability and security and to reduce the impacts and damage caused by power failure or a considerable power imbalance. This study also applies the SPPS scheme to a low-voltage power distribution network with small-capacity backup power source for emergency use to sustain a power supply to small essential loads [5].

The remainder of this paper is organized as follows: applications and circuit designs, application case, and brief conclusions.

II. APPLICATIONS AND CIRCUIT DESIGNS

A. Applications of the SPPS scheme

To apply the SPPS scheme, a changeover switch (COS) is required. Additionally, a phase selector (PHS) may be required to select a phase line from the three phase lines. In the case where a line is firmly connected to the selected phase line, the PHS can be evaded because the three terminals on the source side of the COS are tied together and connected to the PHS or directly to one of the three phase lines. There is no voltage difference between any two phase lines on the load-side terminals of the COS. Therefore, the three-phase loads and single-phase loads between any two phase lines has a de-energized status. In the SPPS operation mode, the single-phase loads between any phase line and the neutral line remain energized. In other words, the power in the SPPS operation mode is continually supplied to (a) the single-phase loads on the secondary side of a single-phase transformer whose primary-side terminals are connected between the phase line and the neutral line of a distribution feeder and (b) the single-phase loads between any phase line and the neutral wire on the secondary side of a three-phase transformer with grounded-wye–grounded-wye (Gnd Y–Gnd Y) connection. The applicable wiring and load connections for applying the SPPS scheme are shown in Fig. 1 [6] [7].

B. Application of the SPPS scheme to three-phase four-wire service in the case where public power generation is inadequate

To apply the SPPS scheme, a three-phase four-wire (3φ4W) service shall be equipped with a COS. In additional, a PHS may be applied to select a line from the three phase lines for load balancing as shown in Fig. 2. One end of the COS is connected to the load side of the feeder circuit breaker (FCB). The three terminals of the other end of the COS are tied together and connected to the PHS or directly connected to one of the three phase lines on the source side of the FCB. The COS must be interlocked with the FCB. Hence, at any moment, only one switch (FCB or COS) can be “on” to avoid a short-circuit accident. The PHS is an optional device and can be used to balance the phase loads in the upstream system. All switches can be designed to operate manually or automatically according to needs.

C. Circuit design for applying the SPPS scheme to single-phase three-wire services with a small emergency backup generator

To apply the SPPS scheme in the case of a bulk power system blackout and when essential loads have to be supplied by a single-phase two-wire (1φ2W) emergency backup generator with limited capacity, the circuit designs for a single-phase three-wire (1φ3W) service with manual and automatic operation devices are shown in Figs. 3 and 4, respectively. When the power supply is switched from the bulk power system to the emergency backup generator, the large loads (such as air conditioners, electric water heaters, and space heaters) connected between any two phase lines are automatically shed. The essential loads connected between any phase line and the neutral line remain energized. The capacity of the emergency backup power supply is controlled by a circuit breaker (44) and an overload relay (45), as shown in Fig. 3 or protected by a special electromagnetic switch (48), as shown in Fig. 4. The rated power of devices (44), (45), and (48) are determined according to the capacity of the emergency backup power source for emergency use.

D. Application of the SPPS scheme to three-phase four-wire services with a small single-phase two-wire emergency backup generator

To apply the SPPS scheme to 3φ4W services in the case of a bulk power blackout and when essential loads need to be fed by a 1φ2W emergency backup generator, circuits with manual and automatic operation functions are designed for 3φ4W service and are shown in Figs. 5 and 6, respectively. The rules and wiring methods are similar to the 1φ3W services, as discussed in the previous section.

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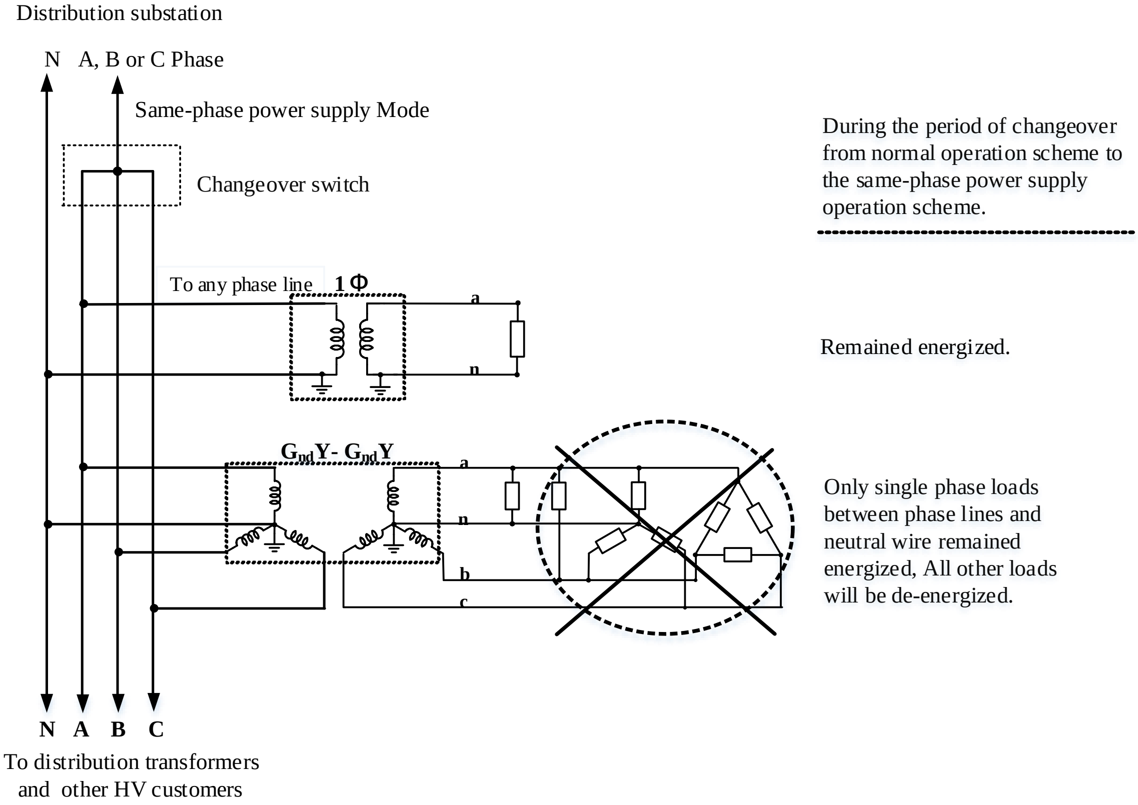

Fig. 1: Applicable wiring and load connections to apply the SPPS scheme

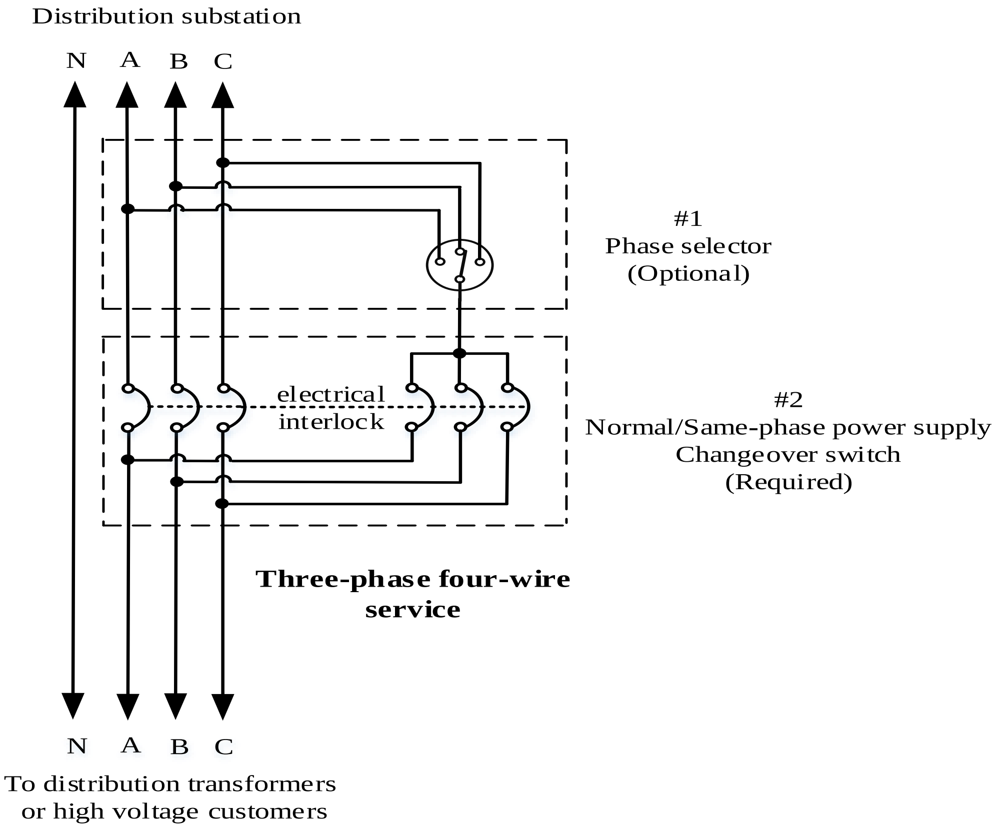

Fig. 2: Circuit for applying the SPPS scheme in a 3φ4W service

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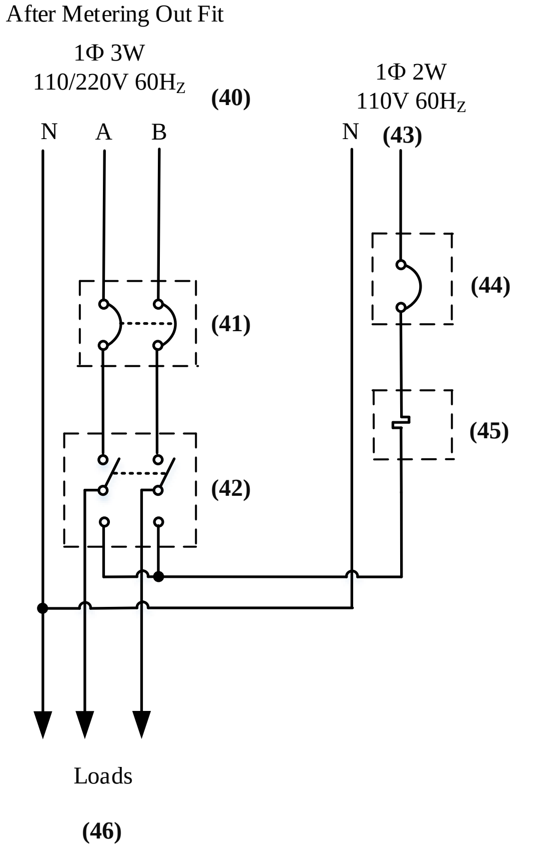

Fig. 3: Circuit with manual operation function designed for 1ϕ3W services

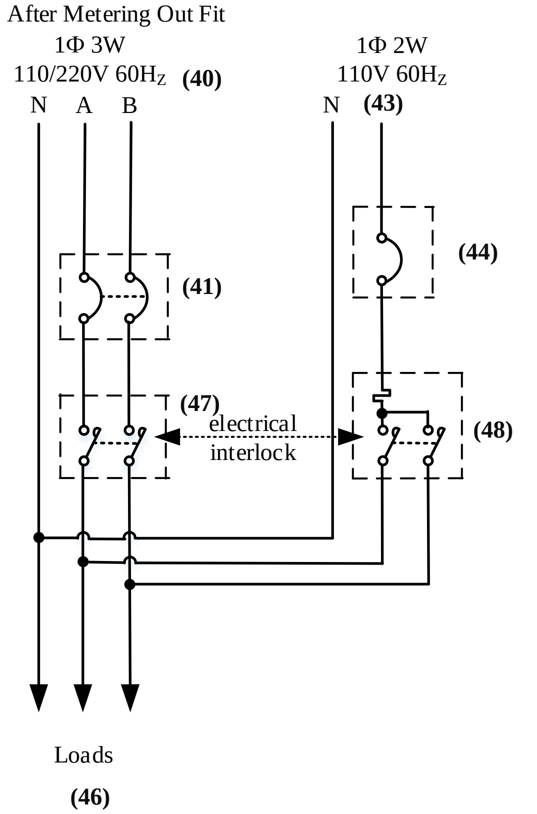

Fig. 4: Circuit with automatic operation function designed for 1ϕ3W services

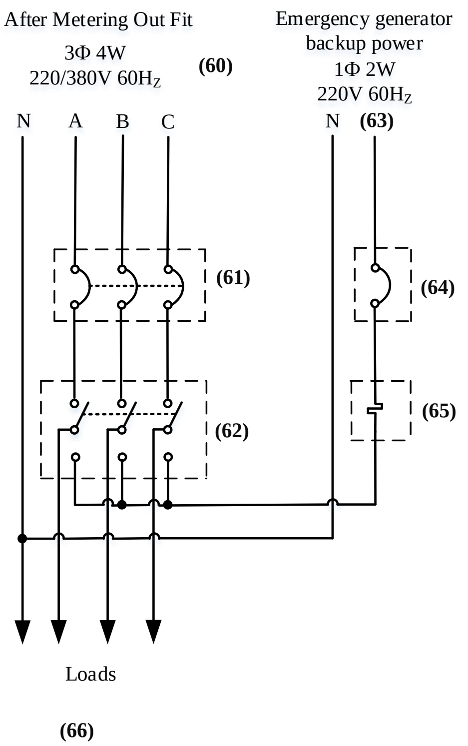

Fig. 5: Circuit with manual operation function designed for 3ϕ4W services

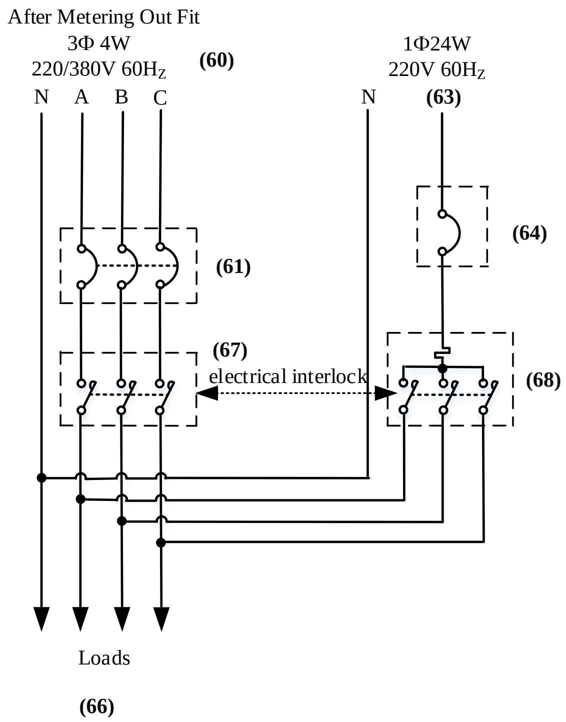

Fig. 6: Circuit with automatic operation function designed for 3ϕ4W services

III. APPLICATION CASE

A. Circuit design for an application case in a low-voltage power distribution system

This section presents an example to illustrate the application and circuit design of the SPPS scheme for a multipurpose low-voltage power distribution system. The example shows the methods and apparatus for applying the SPPS scheme to utilize the emergency backup power generator to supply a large number of distributed small essential loads for basic quality-of-life maintenance. The single-line diagram of the sample system of the application case is shown in Fig. 7. In particular, the intended multipurpose (commercial and residential) building is supplied by 3φ4W 220/380-V services, whereas the individual dwelling units are serviced by 1φ3W 110/220-V services. For simplification, only one representative dwelling unit applying the SPPS scheme is sketched in the single-line diagram. Some loads of the dwelling unit, such as lighting, a refrigerator, and healthcare facilities can be considered as the "secondary often-used essential loads." On the other hand, the loads in the public emergency panel (PEP) can be divided into "often-used essential loads" and "occasional-use essential loads." Because the occasional-use essential loads and often-used essential loads may not be used simultaneously, the reserved power for the occasional-use essential loads can therefore be reassigned to the secondary often-used essential loads. Therefore, the suitable capacity of the backup power generator for emergency use should be the sum of the often-used essential loads and the larger of the occasional-use essential loads and secondary often-used essential loads. It is noted that the secondary often-used essential loads are not the total capacity of all devices in the dwelling unit; otherwise, the capacity of the backup power generator for emergency use will be rather large. The SPPS scheme can effectively restrict and reduce the loading capacity of the power supply in an emergency so that the importance of the secondary often-used essential loads can be regarded as the same as the occasional-use essential loads.

B. Specifics of the circuit design

Figure 7 shows the case where the SPPS scheme is applied during an emergency power supply period. When the public power network is experiences an outage, the occasional-use essential loads such as the fire extinguishing pump can be supplied by the emergency backup generator if needed. However, the fire pump may not be used during the power outage period. The reserved power of the emergency backup generator can therefore be reassigned to the secondary often-used essential loads in the dwelling units. Figure 7 shows that the three-phase power services are changed to 1φ2W 110-V services to limit the power consumption of each dwelling unit to service more dwelling units during the emergency period.

A sufficient amount of power will be reserved for the often-used essential loads. However, the occasional-use essential loads may not be necessary during the period when there is a power outage in the public power system. The residual power can then be reassigned to the secondary often-used essential loads. The control logic of the power supply circuit can be designed case-by-case, e.g., when any occasional-use essential load is operated, all secondary often-used essential loads are de-energized or when some of the secondary often-used essential loads will be de-energized depending on the power required by the occasional-use essential loads at that time. Hence, there will be many combinations of logic control of the electromagnetic switches (MS1–MS3) of the occasional-use essential loads and the circuit breakers of the secondary often-used essential loads.

C. Benefits

According to the rated trip current (AT) of the circuit breakers and the electromagnetic contactors in Fig. 7, the capacity of the circuit breaker (06) in the public emergency panel is 800 A, including the often-used essential loads (50 A + 50 A = 100 A) and the occasional-use essential loads (100 A + 200 A + 400 A = 700 A). According to the system architecture in Fig. 7, when all occasional-use essential loads are idle, the reserved power for emergency use can be transmitted to 180 or more dwelling units. If all 700 A are transmitted, the power is adequate for over 210 dwelling units for a typical dwelling unit in Taiwan. The reserved emergency power can support the lighting and sockets throughout the dwelling unit, except for large loads such as a 220-V air cooler and water heater. However, the 110-V electric fan, electric rice cooker, refrigerator, computer, television, and fax machine are not affected, which ensures a normal life. Figure 7 is shown in Appendix.

IV. CONCLUSION

This paper proposed the planning and design cases of the application of the SPPS scheme to a power distribution system and demonstrated how to classify and group the connection loads. By the SPPS scheme, if the public power system cannot supply an adequate amount of power, it can quickly shed nonessential loads and continually supply power to the essential loads for safety and quality-of-life maintenance. Moreover, by the SPPS scheme, even a small-capacity emergency backup generator can expand its emergency power supply range and distribute power among individual dwelling units for essential power consumption. This scheme can significantly solve the existing power distribution problem in traditional power distribution system designs, especially for businesses and residential buildings. Normal and emergency power supply circuits are separately installed and backup power sources are reserved only for illumination during evacuation, elevators and firefighting and cannot be supplied to dwelling units for safety or basic livelihood needs. The proposed application cases can be useful for future designs of power distribution systems, smart buildings, smart grids and micro grids. Moreover, they can effectively solve the crises caused by power failure and

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emergency power supplies, thereby reducing the impacts and losses of a blackout or rolling blackout.

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AUTHOR BIOGRAPHY

Yu-Wen Huang was born in Taiwan, R.O.C., on May 23, 1953. He received the B.S. and M.S. degrees in electrical engineering from the National Taiwan University of Science and Technology, Taipei, Taiwan, the Republic of China, in 1981 and 2005, respectively. He is now a Ph. D. candidate in Department of Electrical Engineering of National Taiwan University of Science and Technology. His employment experience included CECI Engineering Consultants, Inc., Taiwan from 1981 to presently. His special fields of interest included feasibility study, plan, design, construction supervisory, and project construction management of electrical power distribution system, traction AC power supply system of MRT and railway, central monitoring and control system, traffic surveillance and control system of freeway, and intelligent transportation system etc. Now, his position is associate vice president. His research interests include electrical power distribution system, microgrid, electrical power transmission feeder automation system, modeling and simulation of power distribution system, and the same phase power supply system etc.

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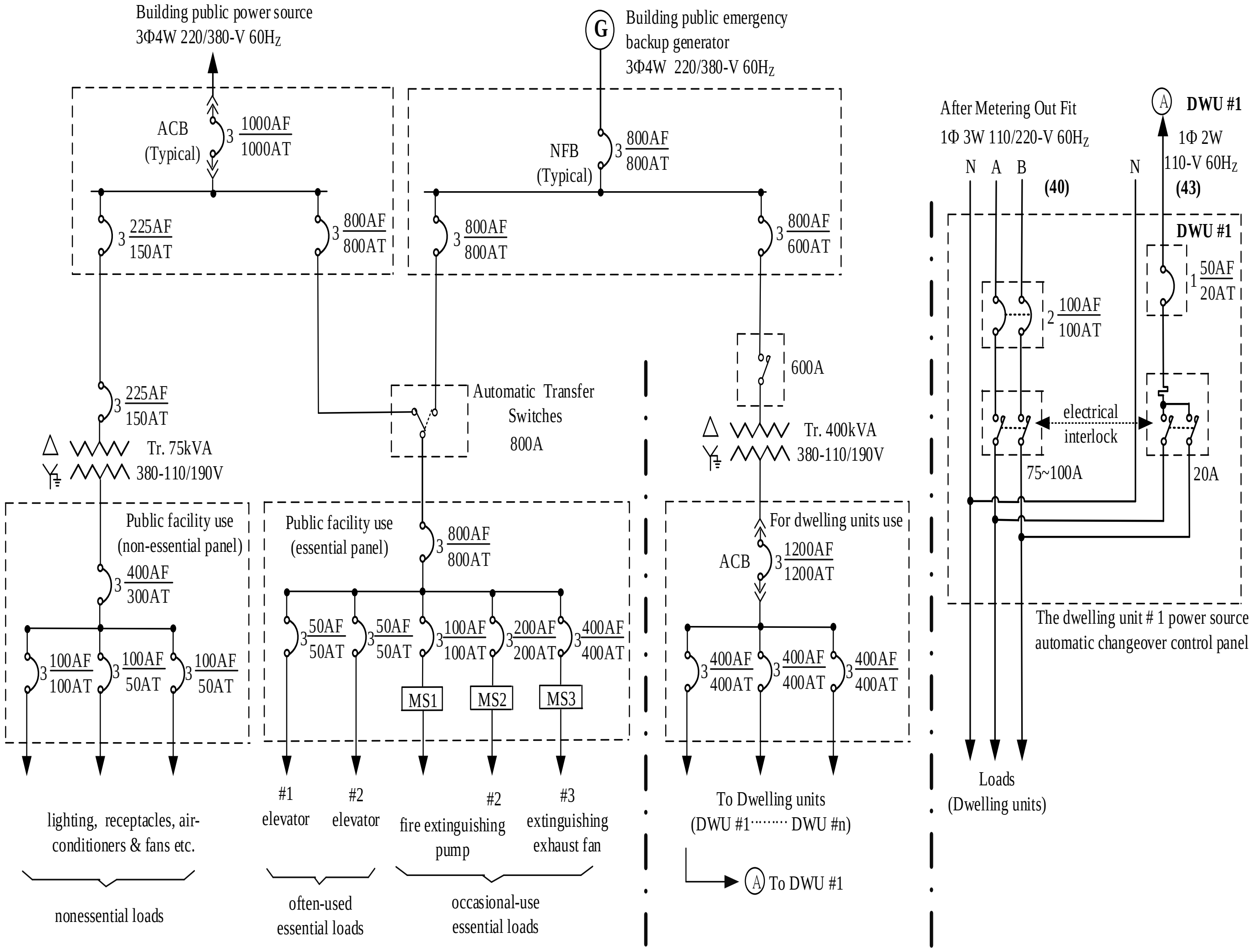

Fig. 7: Single-line diagram of application of the SPPS scheme during an emergency power supply period