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Performance Analysis of 100 KVA Generator Set as AC Backup Supply at Panakukang Electrical Substation

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Substation AC backup supply reliability is critical for sustaining auxiliary equipment operation during grid blackouts. Prior studies on genset sizing and motor starting have not specifically addressed substation AC backup systems integrating continuous loads, non-continuous motor loads, and comparative starting methods. This study evaluates the adequacy of the existing 100 kVA prime / 110 kVA standby genset at Panakkukang Substation using field data collection and ETAP 19.0.1 simulation. The total continuous load is 9.342 kW, requiring a minimum genset capacity of 11.675 kW after applying a 46.7% demand factor and 125% safety factor (per NFPA 110 and ISO 8528-1). The existing genset adequately covers continuous loads at only 10.62% of standby capacity. However, simultaneous starting of the hydrant and oil pump motors exceeds genset capability under all methods tested: Direct-On-Line (DOL) causes a 24.00% voltage dip requiring 463.74 kVA; Wye-Delta reduces voltage dip to 17.48% requiring 231.87 kVA; and VFD limits voltage dip to below 3% requiring only 159.17 kVA, compliant with IEEE Std 1159-2019. This study recommends upgrading genset capacity to at least 160 kVA and adopting VFD motor starting to ensure reliable substation AC backup supply.

Keywords: Generator Set, Substation AC Backup Supply, Reliability, Blackout, Variable Frequency Drive (VFD)

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1. INTRODUCTION

The reliability of power systems in substations is an important factor in ensuring the continuity of electrical energy distribution services to customers. Per ISO 8528-1 [13] and IEEE Std 1159-2019 [14], generator sets used as backup power sources must be sized and operated to maintain power quality and reliability under all load conditions. One aspect supporting this reliability is the availability of an alternating current (AC) power supply system capable of supplying operational supporting equipment in substations during disturbances in the main grid supply. Under blackout conditions, the presence of a generator set (genset) as a backup power source becomes essential to maintain the operation of critical equipment, such as lighting systems, air conditioning, control panels, and other supporting devices [5], [9]. Therefore, the genset capacity must be sufficient to meet load requirements in order to maintain the operational reliability of the substation.

Several previous studies have discussed genset utilization as backup power in electrical installations by considering loading, demand factors, and motor load characteristics [1], [3], [7]. Zhang et al. [1] proposed a starting capability assessment method for induction motors in islanded microgrids, while Rodrigues et al. [3] developed a convex model for motor starting transients in optimal power flow. Asainov and Shekari [8] investigated diesel generator quantity optimization considering induction motor start-up. However, these studies focused on microgrid and industrial settings rather than substation AC auxiliary systems. Studies specifically evaluating genset adequacy in substation AC backup supply systems while simultaneously considering continuous load characteristics, non-continuous motor loads, and a comparative analysis of DOL, Wye-Delta, and VFD starting methods remain limited. Furthermore, no prior work has applied ETAP-based simulation to evaluate the combined effect of motor starting methods on voltage dip and genset sizing within a substation context.

Currently, the Panakkukang Substation uses a genset as an AC backup supply source to maintain equipment operation during blackout conditions. However, no comprehensive study has been conducted to evaluate the capability of the existing genset in supplying both continuous and non-continuous loads involving hydrant pump and oil pump motors. This condition raises questions regarding whether the available genset capacity is sufficient to ensure system reliability under all operating conditions, as well as how motor starting methods affect the required genset capacity.

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This study was conducted through field observations, load data collection, interviews, documentation, and technical analysis using ETAP 19.0.1 software [10], [12]. The analysis covered total continuous loads, demand factors, and motor starting characteristics using several starting methods, namely Direct On Line (DOL), Wye-Delta, and Variable Frequency Drive (VFD). Through this approach, an overview was obtained regarding the capability of the existing genset to supply load requirements and the minimum genset capacity required to support reliable system operation during blackout conditions.

The novelty of this study lies in its integrated evaluation framework for AC backup supply genset adequacy in substations, combining: (1) continuous load demand factor analysis, (2) non-continuous motor load starting current analysis using DOL, Wye-Delta, and VFD methods, and (3) ETAP 19.0.1 simulation for voltage dip assessment under motor starting conditions. The specific research problem addressed is: Is the existing 100 kVA (prime) / 110 kVA (standby) genset at Panakkukang Substation sufficient to supply all loads during blackout conditions, and which motor starting method is most effective for ensuring system reliability? The objectives are to: (1) evaluate continuous load demand and genset loading level, (2) quantify voltage dip and required genset capacity for each starting method, and (3) recommend an optimal genset capacity and starting method. The contribution of this study is a replicable case-study methodology for substation genset sizing that can serve as a reference for substation planning. This paper is organized as follows: Section 2 describes the research method, Section 3 presents results and discussion, and Section 4 states the conclusions.

2. METHOD

This study is a quantitative research with a case study approach conducted on the AC backup supply system of the Panakkukang Substation, Makassar City. The study aims to evaluate the adequacy of the existing generator set (genset) capacity in supplying loads during blackout conditions and to determine the required genset capacity based on load characteristics and motor starting methods. The analysis was carried out using technical calculations and power system simulations with ETAP 19.0.1 software [10], [12]. The existing genset has the following specifications: prime power of 100 kVA (80 kW) and standby power of 110 kVA (88 kW), nominal voltage of 400 V (three-phase), nominal frequency of 50 Hz, rated power factor of 0.8, and subtransient reactance (X"d) of approximately 0.12 per unit as per manufacturer documentation. The genset is equipped with an automatic voltage regulator (AVR) and an isochronous governor to maintain voltage and frequency stability during load transients.

The research was conducted at the Panakkukang Substation, Makassar City. The research data consisted of primary and secondary data. Primary data were obtained through field observations and interviews with substation operational personnel. Secondary data were collected from technical documents, including genset specifications, AC equipment load data, hydrant and oil pump motor data, genset output data, and the single line diagram of the substation electrical system.

The collected data included genset capacity, installed power of each load, operating characteristics of continuous and non-continuous loads, demand factors, and motor parameters used in starting current analysis [1], [3]. Continuous loads were further classified by load type and operating priority: lighting, SCADA, and battery-charger/UPS circuits are classified as critical, always-on loads (priority 1), while control-panel and HVAC circuits are classified as essential but cyclical loads (priority 2) with an individual diversity factor of approximately 0.6–0.8 reflecting intermittent operation. Motor data used in the analysis include: rated output power (kW), efficiency, rated power factor, locked rotor current (LRC) multiplier of 6× rated current (per NEMA Design B standard), starting current multiplier, rotor inertia (WK^2) of approximately 1.2–1.8 $kg \cdot m^2$ as estimated from manufacturer pump-motor datasheets, and estimated starting duration of 5–10 seconds. The maximum allowable voltage dip during motor starting was set at 15% of nominal voltage, in accordance with IEEE Std 1159-2019 recommendations for power quality in industrial and utility systems [14]. The ETAP model was built based on the substation single-line diagram, incorporating bus voltage levels (400 V), cable impedance parameters, transformer ratings, and individual load data. Two simulation modes were used: load flow analysis (Newton-Raphson method) to evaluate continuous load conditions, and motor starting analysis to evaluate voltage dip and transient loading for each starting method. The 125% safety factor applied to the demand calculation is consistent with the IEEE Std 446 recommendation for emergency and standby power systems [6], as well as the NFPA 110 standard. The 70% maximum generator loading criterion follows ISO 8528-1 [13] guidance to avoid overloading and thermal stress on the genset under emergency conditions.

The research stages are shown in Figure 1. The study began with a literature review to obtain the theoretical basis regarding backup power supply systems, genset capacity, load analysis, induction motor characteristics, and power system simulation using ETAP [7], [10], [11].

Furthermore, field observations and technical data collection of the AC backup supply system at the Panakkukang Substation were conducted. The obtained data were then used to calculate the total continuous load and identify non-continuous loads affecting genset capacity. The non-continuous loads in this study consist of the hydrant pump and oil pump motors, which are assumed to start simultaneously representing the worst-case scenario for genset loading during an emergency. This assumption was confirmed through interviews with substation operational personnel. Afterward, the system was modeled based on the single line diagram using ETAP 19.0.1 software [10], [12].

The next stage involved simulating the capability of the existing 100 kVA genset in supplying substation loads during blackout conditions. The simulation results were used to evaluate the genset loading level through load flow analysis [4], [11]. Subsequently, genset capacity requirements for non-continuous loads were analyzed by considering several motor starting methods, namely Direct On Line (DOL), Wye-Delta, and Variable Frequency Drive (VFD) [1], [3].

If the simulation results indicated that the genset capacity did not meet system requirements, several alternative genset capacities were simulated until the minimum capacity capable of safely supplying all loads was obtained. The final stage of the study involved analyzing the simulation results and formulating recommendations for the appropriate genset capacity to improve the reliability of the AC backup supply system at the Panakkukang Substation. Validation of the ETAP simulation results was performed by comparing the simulated continuous load values and bus voltage with operational measurement data recorded at the substation. The load flow simulation result of 9.38 kW was verified against the actual logged demand of 9.342 kW, confirming acceptable agreement (deviation < 0.5%).

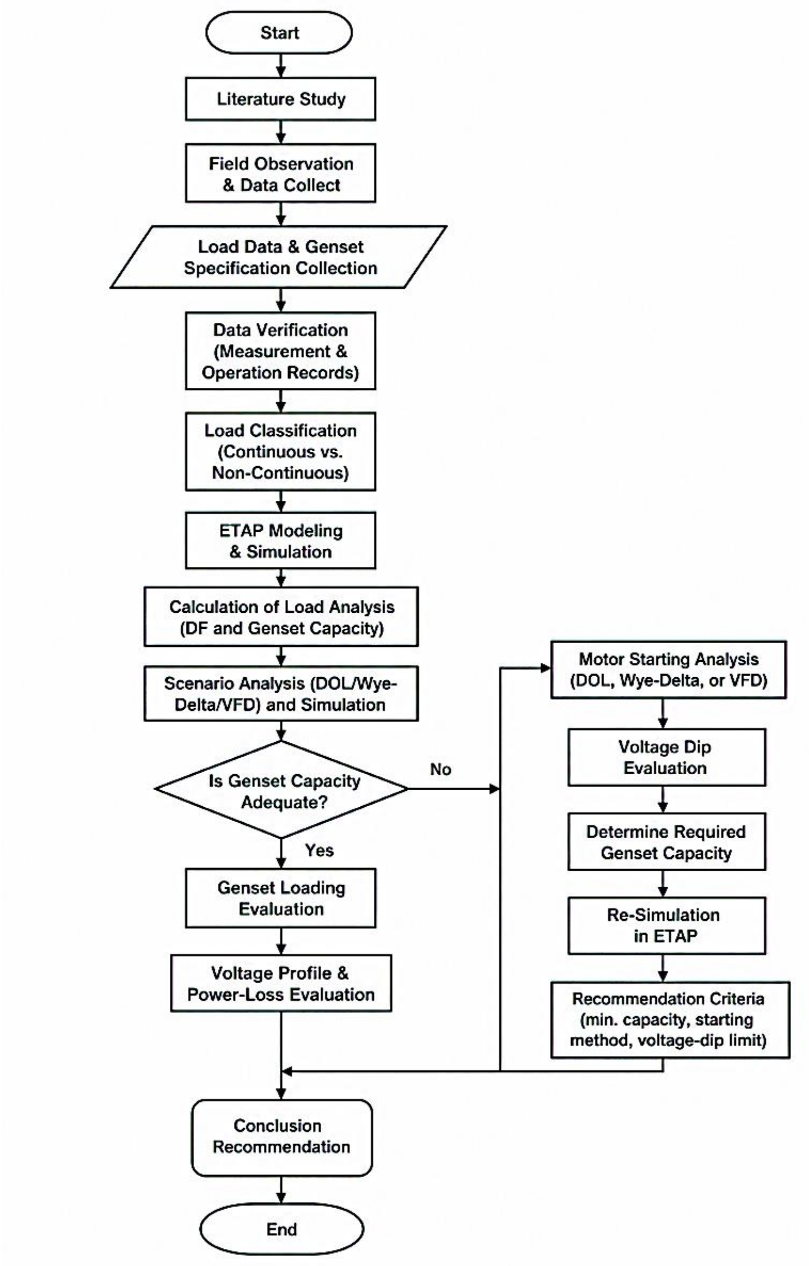

Figure 1. Research Flowchart

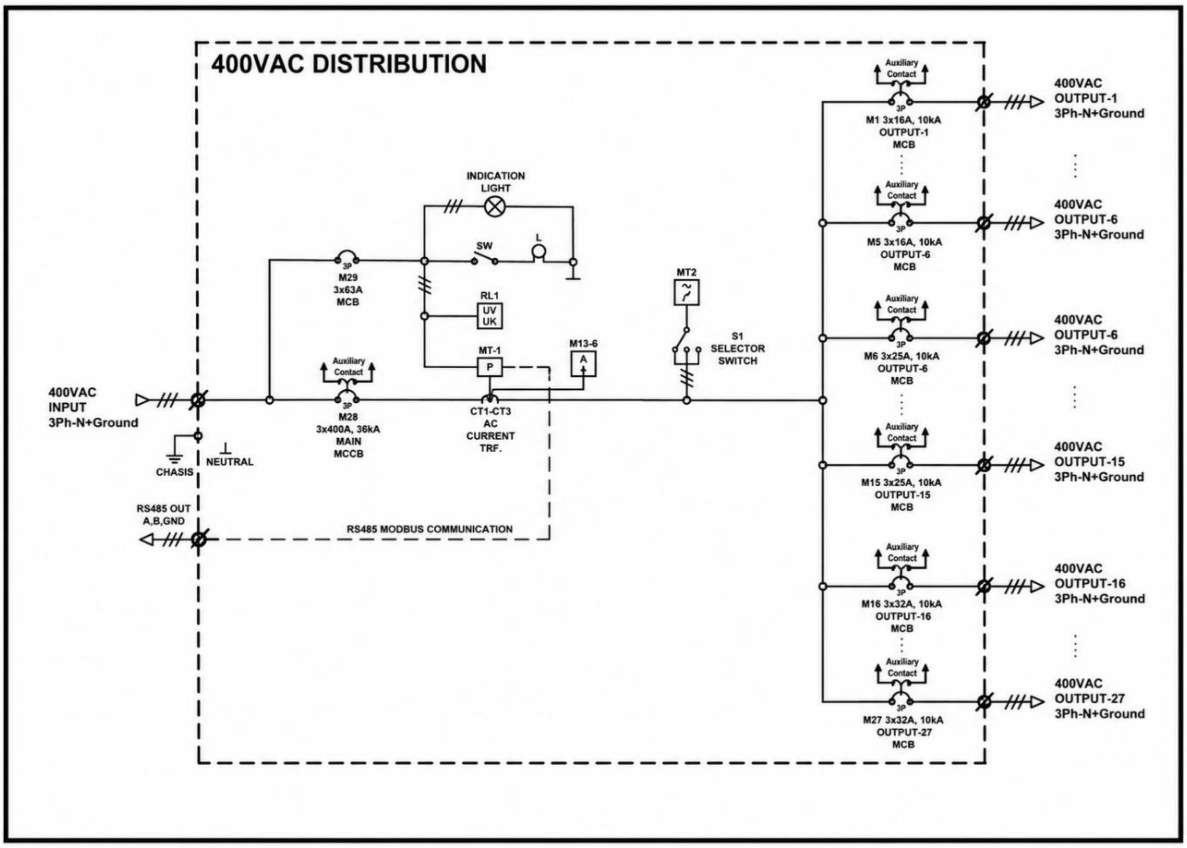

Figure 2. Single Line Diagram of the AC Backup Supply System at Panakkukang Substation

3. RESULTS AND DISCUSSION

3.1. Continuous Load Analysis

The evaluation of genset capacity began with the identification of continuous loads that must remain operational during blackout conditions. The continuous loads at the Panakkukang Substation consist of loads connected to Panel PS#1 and Panel PS#2, with a total active power of 9.342 kW. The summary of continuous loads is presented in Table 1.

Table 1. Summary of Continuous Loads at the Panakkukang Substation

Panel	Active Power (kW)
PS#1	1,462
PS#2	7,880
Total Continuous Load	9,342

Based on Table 1, the total actual power demand that must be supplied during emergency conditions is 9.342 kW. Furthermore, the demand factor was calculated to determine the utilization level of the installed load using Equation (1).

$$DF = \text{Maximum Demand} / \text{Connected Load} \quad (1)$$

where:
DF = Demand Factor (%)
Maximum Demand = maximum actual load (kW)
Connected Load = total installed load (kW)

The demand factor calculation parameters are presented in Table 2.

Table 2. Demand Factor Calculation Parameters

Parameter	Value
Connected Load	20 kW
Maximum Demand	9,342 kW
Demand Factor	46,7 %

Based on the data in Table 2, the demand factor is calculated as follows: DF = 9.342/20 = 0.467 = 46.7%. This value indicates that the actual load utilization is only approximately half of the total installed capacity, reflecting the nature of substation auxiliary loads where not all equipment operates simultaneously.

$$DF = 9{,}342 / 20 = 0{,}467 = 46{,}7\% \quad (2)$$

The demand factor value of 46.7% reflects typical substation auxiliary load characteristics, where lighting, control panels, and SCADA systems operate continuously while HVAC and other equipment cycle on and off.

To determine the minimum genset capacity, a safety factor of 125% was applied. Therefore, the required power capacity was calculated using Equation (3).

$$\text{Power Capacity} = DF \times \text{Connected Load} \times \text{Safety Factor} \quad (3)$$

$$\text{Power Capacity} = 0{,}467 \times 20 \times 1{,}25 = 11{,}\ 675\ \text{kW} \quad (4)$$

The results of the genset power requirement calculation are shown in Table 3.

Table 3. Genset Power Requirement Calculation Results

Parameter	Value
Demand Factor	46,7 %
Connected Load	20 kW
Safety Factor	125 %
Required Genset Power	11,675 kW

The results indicate that the power requirement for supplying all continuous loads is only 11.675 kW. Meanwhile, the existing genset has a prime power capacity of 100 kVA (80 kW) and a standby power capacity of 110 kVA (88 kW), as shown in Table 4.

It is important to clarify the relationship between the real power (kW) values used for load demand and the apparent power (kVA) rating used for genset capacity. Genset nameplate capacity is rated in kVA because it reflects the alternator's maximum current-handling capability regardless of load power factor, whereas the connected load is expressed in kW (real power actually consumed). The two are related through kVA = kW / PF, where PF is the power factor of the load. At the genset's rated PF of 0.8, the standby capacity of 110 kVA corresponds to 88 kW of real power output; this is the basis for the kW figures used for the genset in Table 4. Because the continuous-load demand factor and safety factor in Equation (3) are computed in the kW domain, while the motor running-load and starting-capacity requirements in Section 3.3 are computed in the kVA domain (since motor loads operate at a lower PF, typically 0.85, and starting current is dominated by reactive components), the two figures are not directly interchangeable and must each be compared against the genset rating expressed in the same unit.

Table 4. Existing Genset Specifications

Parameter	Value
Prime Power	100 kVA (80 kW)
Standby Power	110 kVA (88 kW)

Based on this comparison, the existing genset capacity is significantly higher than the continuous load requirement and is therefore highly adequate to serve as the AC backup power supply source at the Panakkukang Substation.

3.2 System Simulation Results Using ETAP 19.0.1

Validation of the calculation results was carried out through load flow simulation using ETAP 19.0.1 software. The simulation was used to evaluate voltage profiles, active power, reactive power, and power losses in the distribution system [4], [10], [12]. The simulation results are presented in Table 5.

Table 5. Load Flow Simulation Results

Parameter	Value
Total Active Power	9,38 kW
Total Reactive Power	3,34 kVAR
Main Bus Voltage	398 V
Voltage Percentage	99,5 %
Power losses	0,051 kW
System Efficiency	99,59 %

The simulation results show that the main bus voltage remains at 99.5% of the nominal voltage (398 V out of 400 V nominal), which is well within the +/-10% tolerance specified by IEEE Std 1159-2019. Power losses are only 0.051 kW, or approximately 0.54% of total supplied power, indicating very low resistive losses in the low-voltage distribution system. The system efficiency of 99.59% confirms that the distribution network operates optimally under continuous loading conditions. These results are consistent with the theoretical expectation that a lightly-loaded system exhibits minimal voltage drop and power loss.

When the system operates using the genset, the generator loading level is only approximately 10.62% of its nominal standby capacity, as shown in Table 6. This extremely low loading level (far below the recommended minimum of 30% for diesel gensets per ISO 8528-1) warrants attention from an operational perspective, as sustained low-load operation can lead to wet stacking (unburned fuel accumulation in exhaust) and accelerated engine wear. Substation operators should consider periodic load testing at higher levels to maintain genset health.

Table 6. Genset Loading Evaluation

Parameter	Value
Genset Standby Capacity	110 kVA
Continuous Load	11,675 kW
Loading Level	10,62 %

These results demonstrate that the existing genset is fully capable of maintaining power supply continuity for all continuous loads during emergency conditions. The high margin between genset capacity (88 kW standby) and actual continuous demand (9.342 kW) means the genset can comfortably absorb load growth of up to 800% of current demand before reaching the 70% loading limit. This large margin exists because the genset was likely sized to handle potential future motor starting loads rather than current continuous loads alone.

3.3 Motor Starting and Genset Capacity Analysis

In addition to supplying continuous loads, the genset must also be capable of supplying non-continuous loads in the form of hydrant pump and oil pump motors. Induction motors draw starting currents of 5–8 times rated current during direct-on-line starting (per NEMA MG-1 standards), which imposes a severe transient load on the genset. Unlike the utility grid with virtually infinite fault capacity, a diesel genset has a limited transient current capability determined by its subtransient reactance (X”d), AVR response time, and governor droop characteristics. This fundamental difference explains why the existing genset, although adequate for continuous loads, faces challenges when motor starting loads are added [1], [3], [8]. The motor running load data are presented in Table 7.

Table 7. Motor Running Loads

Motor	Output Power (kW)	Running Load (kVA)
Hydrant Pump #1	37,00	48,37
Hydrant Pump #2	59,13	77,29
Oil Pump	3,00	3,92
Total	99,13	111,42

Based on Table 7, the total motor running load is 111.42 kVA. By applying the maximum genset loading limit of 70% (per manufacturer recommendation and ISO 8528-1 guidelines), the minimum genset capacity to support motor running conditions was calculated. It is important to note that 159.17 kVA represents the minimum genset capacity required to sustain motor running loads within the 70% loading limit, not the capacity required during the motor starting transient. The starting transient demands significantly higher capacity, as analyzed in Table 8.

$$\text{Genset Capacity} = \text{Total Running Load} / 70\% \tag{5}$$

$$\text{Genset Capacity} = 111{,}42 / 0{,}70 = 159{,}17\ \text{kVA} \tag{6}$$

The calculation results indicate that the recommended minimum genset capacity for supplying motor loads is 159.17 kVA. The effect of motor starting methods on genset capacity requirements is presented in Table 8.

Table 8. Comparison of Genset Capacity Requirements Based on Starting Methods

Starting Method	Required Capacity (kVA)
Direct-On-Line (DOL)	463,74
Wye-Delta	231,87
VFD	159,17

In addition to affecting genset capacity, the starting method also influences the voltage dip occurring during motor startup.

Table 9. Voltage Dip Analysis Results

Starting Method	Voltage Dip (%)
DOL	24.00
Wye-Delta	17.48
VFD	<3.00 (negligible)

Based on Tables 8 and 9, a clear comparison emerges among the three starting methods. The DOL method, while simplest, produces a 24.00% voltage dip which far exceeds the 15% limit recommended by IEEE Std 1159-2019, and requires 463.74 kVA more than four times the existing genset capacity. This confirms that DOL starting of these motors is technically infeasible with the existing or even a moderately upgraded genset. The Wye-Delta method reduces the voltage dip to 17.48% and the required genset capacity to 231.87 kVA (approximately 50% reduction compared to DOL), consistent with the theoretical 1/3 reduction in starting current characteristic of star-delta starting. However, the voltage dip still exceeds the 15% limit, and the method introduces a switching transient when transitioning from wye to delta configuration that may briefly interrupt motor torque. The VFD method limits the motor starting current to rated current (100% torque control), resulting in a voltage dip below 3% well within acceptable limits per IEEE Std 1159-2019 and a required genset capacity of only 159.17 kVA, consistent with findings reported by Zhang et al. [1] who demonstrated superior voltage stability in VFD-equipped islanded systems. These results are also aligned with Asainov and Shekari [8], who showed that soft-start methods substantially reduce the number and size of required generators in industrial installations [1–3].

The results of this study confirm that the existing 100 kVA (prime) / 110 kVA (standby) genset adequately supplies continuous loads at Panakkukang Substation. However, it is insufficient to simultaneously start the hydrant pump and oil pump motors under any of the three starting methods analyzed. From a practical operational standpoint, this means the substation should implement a sequential motor starting protocol — starting the oil pump first, then the hydrant pump — which can reduce peak genset loading significantly. In parallel, the most effective long-term solution is to increase genset capacity to at least 160 kVA and install VFD units for both pumps, which eliminates voltage dip issues and reduces genset sizing requirements while also providing variable speed control benefits for pump efficiency. The cost of VFD installation is typically offset by energy savings and reduced mechanical wear on the pumps. It is important to note that the findings are specific to this single substation and should not be generalized without applying the same evaluation framework to other substations with different load profiles.

4. CONCLUSION

This study evaluated the adequacy of the existing 100 kVA (prime) / 110 kVA (standby) genset as an AC backup supply at Panakkukang Substation using technical calculations and ETAP 19.0.1 simulations. Three main conclusions are drawn. First, the existing genset is fully adequate for supplying continuous loads: the total continuous demand of 9.342 kW represents only 10.62% of the genset's standby capacity, with bus voltage maintained at 99.5% of nominal and system efficiency at 99.59%. Second, the existing genset is insufficient for simultaneous motor starting: the hydrant pump and oil pump combination requires 159.17 kVA (VFD), 231.87 kVA (Wye-Delta), or 463.74 kVA (DOL) — all exceeding the existing 110 kVA standby capacity. Third, among the three starting methods evaluated, VFD produces the best performance: voltage dip below 3% (within IEEE Std 1159-2019 limits), compared to 17.48% for Wye-Delta and 24.00% for DOL, both of which exceed the recommended 15% limit. Based on these findings, the study recommends: (1) increasing the genset capacity to at least 160 kVA, and (2) installing VFD units for both the hydrant pump and oil pump motors. As an interim operational measure, sequential motor starting (oil pump first, then hydrant pump) is recommended to reduce peak genset transient loading. The primary contribution of this study is a replicable evaluation framework for substation AC backup genset sizing that integrates demand factor analysis, motor starting current analysis, voltage dip assessment, and ETAP simulation. The main limitation is that findings are based on a single substation case study; generalization to other substations requires application of the same framework with site-specific load data. Future research may extend this framework to include temperature derating factors, load growth projections, and economic cost-benefit analysis of VFD versus alternative soft-start methods.

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