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DESIGN AND EXPERIMENTAL EVALUATION OF A PARALLEL OPERATION OF 2X MOBILE DG'S WITH DIFFERENT RATINGS

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Abstract
The mobile diesel generators are common place in construction, mining, disaster recovery and remote operation and any industry where the required load cannot be achieved by generator and therefore, the operation requires parallel operation. Multi-generation systems have the advantages of capacity increment, enhanced reliability, and fuel efficiency. Similar operation of DGs with varying ratings is also a challenge especially in synchronization and load sharing. Synchronization is to make sure that voltage, frequency and phase angle are similar prior to interconnection. The sharing of the load between unequal generators should be carefully controlled to avoid overloading smaller generators and underexploiting larger ones.Conventional techniques tend to assume that the rating of generators is identical, so they cannot be used in mixed arrangements.

INTRODUCTION

Parallel operation Generators Two or more generator sets are synchronized to provide power to common loads, that is, one generator matches the electrical parameters of another power source (such as a power grid or another generator) and then they are connected together. In industry and commercial power power plants, there can be many generators running parallel (also known as generator paralleling) to boost capacity, improve reliability or facilitate maintenance.

1.2 2 Project Background

Mobile diesel generator (DGs) are commonly used to provide power where grid power is not available, like a construction site, mine, disaster recovery, and remote operation, and synchronization with another power source (such as a power grid or other generator) is synchronized before two units are connected (when all units are synchronized well). But in most cases a single generator may not be capable of carrying the full load requirement hence parallel operation is needed. Parallel running of generators would boost the total power capacity, enhance system reliability and guarantee a better fuel efficiency.

1.3 3 Project Objectives

The main objectives of project are given below:

- Implement parallel operation between two mobile dgs of different ratings.

- To achieve proper synchronization and safe load sharing.
- Enhance power reliability and availability in offgrid and emergency scenarios.

1.4 4 Project Description

Generator synchronization is the synchronization of important electrical parameters of a generator with those of a live power system to enable safe connection between them. Practically, this is a way of matching the voltage, frequency, and phase angle (and in the case of a three-phase system, phase sequence) of a generator to that of the system into which it will be connected. When two AC generators (or a generator and the grid are synchronized), the voltage waveforms in each other will be increased If they are not synchronized, fault currents will be large, and may cause serious equipment damage. Lack of adequate Load sharing control will lead to overloading of smaller generators and underutilization of the bigger units hence inefficiency and possible failure of the equipment.

2. Literature Review

Generators concept are compatible provided they are capable of working in parallel such that they do not harm or destroy neutral currents that flow between them. Neutral current flow between generator sets is not always harmful depending on the nature of temperature rise of the generator set, age and insulating ratings, but neutral currents may result in inaccurate operation of protective relays especially in sense of ground faults. Generators may be connected with a neutral current when the voltage of two machines is not the same. The voltage difference may be due to error in the kVAR load sharing adjustments, or may be due to the variation in the shapes of the voltage waveforms caused by variations in the alternator voltage harmonics.
In the event of incompatibility of alternators manifested in an operating system (e.g., inability to adjust current flow by sharing of kVAR loads), harmonic analysis test of the neutral current flow between the machines when it is fed with a balanced linear load (or even no load) can be performed. In the event the fundamental frequency of current corresponds to the same frequency that the system operates at, the current flow is an effect of inaccurate kVAR load sharing. When the basic frequency is 150 or higher the current flowing is certainly caused by alternator incompatibility and there is a need to decide how to handle it. The differences between the shape of the voltage waveform occurring between two (or more) paralleled machines cause harmonic neutral current flow.

2.1 1 Distributed Generation Overview

Distributed generation (DG) is a concept that is used to refer to small scale power generating units that are located near the load center as opposed to centralized power generation plant, DG systems minimize transmission losses, enhance reliability and back-up power during blackout. DG technologies consist of diesel generators, gas turbines, solar pv, wind turbines and micro hydro. Among these diesel generators simply will not disappear because they can provide a reliable power supply under different conditions.

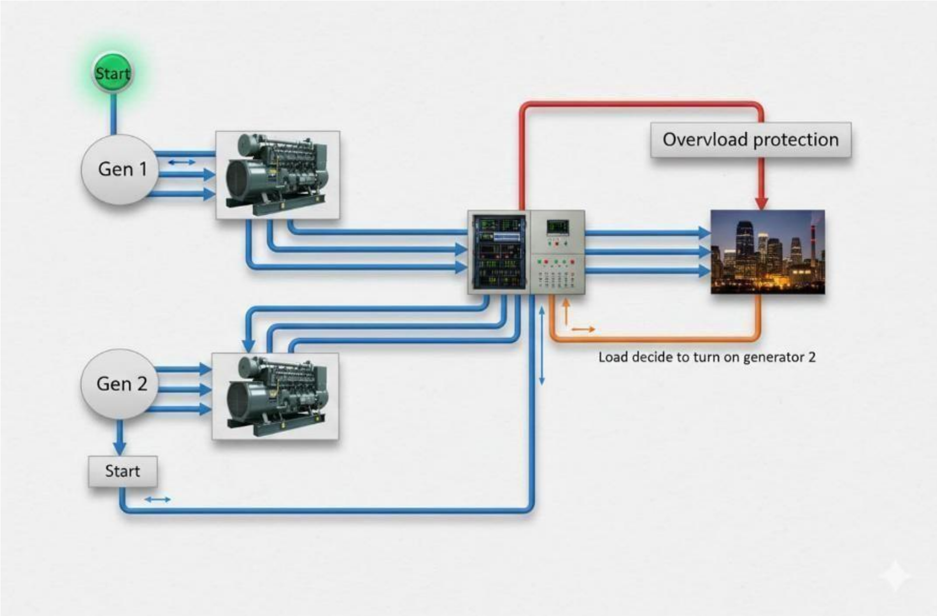

Figure 1a. Parallel operation of 2x mobile DG's

2.2 Need For Parallel Operation

Requirement of parallel Operation parallel operation of alternators is necessitated by a number of operational and economical benefits that it provides. Among them are Increased Reliability, Parallel operation will ensure that when one of the alternators fails to perform its duty, the other alternators will still be able to supply power, hence, greatly improving the reliability of the power system.The voltage on each component is the same as that of the source voltage hence, the components can also work well.

2.3 3 Synchronization Techniques

The synchronization is to make sure that generators are connected to the same voltage, frequency and phase angle. The lack of synchronized synchronization may lead to: Circulating currents. Voltage instability. Mechanical stress.

Methods:

2.3.1 Manual Synchronization

The synchronization is done manually by using where the instruments are observed and the generator is manually controlled. Aimed actions in the process of manual syncing are the throttle and voltage adjustment; and making a decision as to when the breaker is to be closed. In the past, operators made a judgment of synchronization by the use of indicator lamps and analog meters.

2.3.2 Automatic synchronization

Microprocessor-based systems. To achieve the process with high accuracy and repeatability, most contemporary systems of generators incorporate automatic synchronizing equipment. An automatic synchronizer is simply a controller or relay which assumes the control processes of changing speed, changing voltage, and closing the breaker at the appropriate moment.

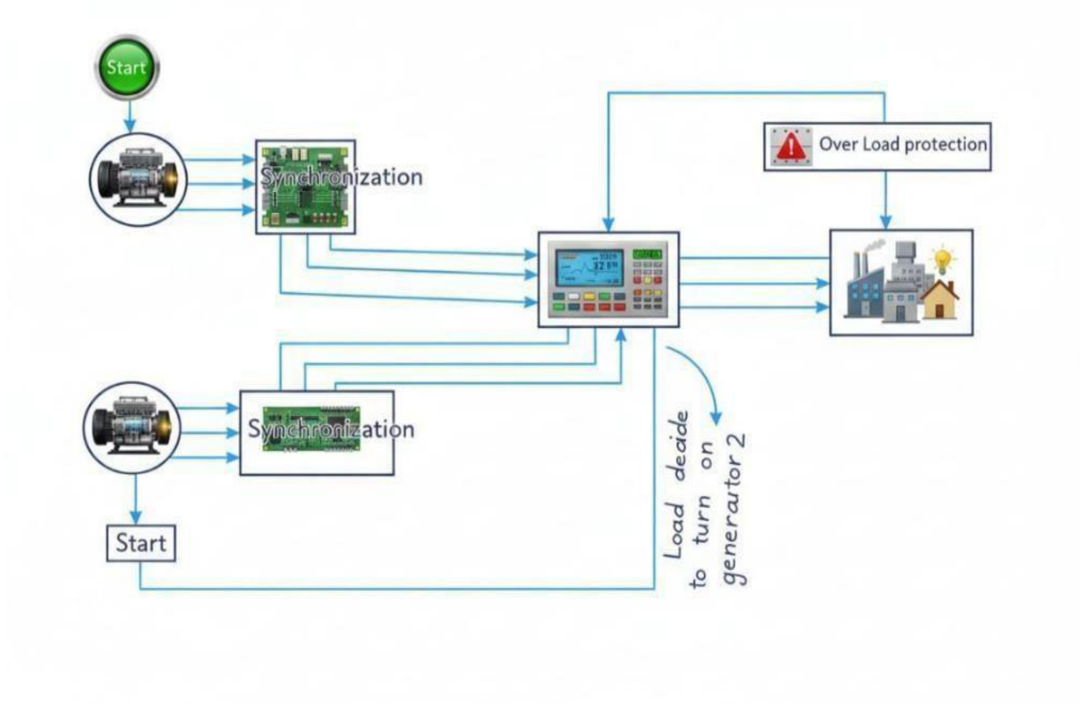

Figure 2b. Synchronization between two DG's

2.4 Load sharing Method

Isolated bus paralleling has traditionally been carried out by droop governing and voltage regulation systems, since these systems can achieve acceptable load sharing between any two or more generators sharing a common isolated bus, provided the generators can be configured to droop frequency and voltage at a similar rate, and that the control can be adjusted to stable frequency and voltage values. The same speed and voltage drop would cause the same load sharing between parallel sets of generators. The same can be applied to the voltage regulation system of the generator sets in a system. The droop-based var load sharing is commonly referred to as reactive droop compensation. Frequency and voltage common droop settings may vary and are normally within range of 3-5% between no load to full load.

The changes of voltage that can take place under operation of droop at this point are not critical. in remote bus systems, however the frequency variations that happen can be disruptive to. 1 operation of certain loads, particularly in emergency/standby systems where the load may change quite significantly over time. Attended prime power applications are often shared by droop loading. The droop governing approach is typically applicable to the control of loading of generators used in single generator set-to-utility paralleling systems since the utility frequency tends to be very constant. However, reactive droop cannot be used to utility paralleling because of the vastly different voltage level at any point in a utility distribution system as the load on the system varies. The generators, when paralleled with a utility source, must have var/power factor controllers.

2.5 Control Strategies

- Digital Controllers:For synchronization and load sharing.
- Arduino: Advanced algorithms for dynamic load management.

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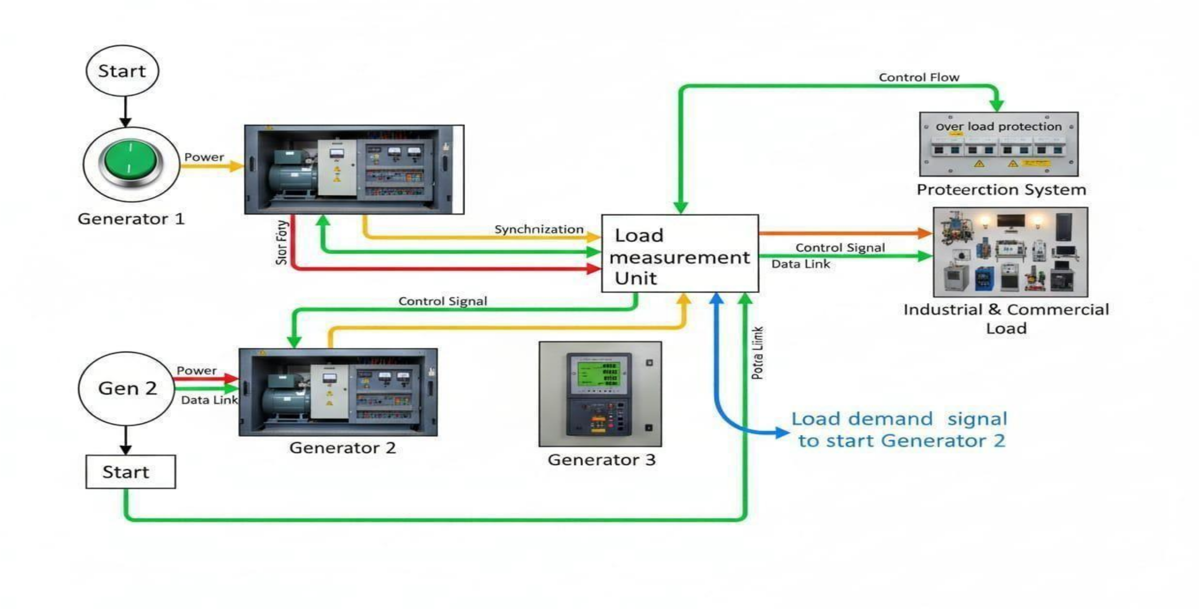
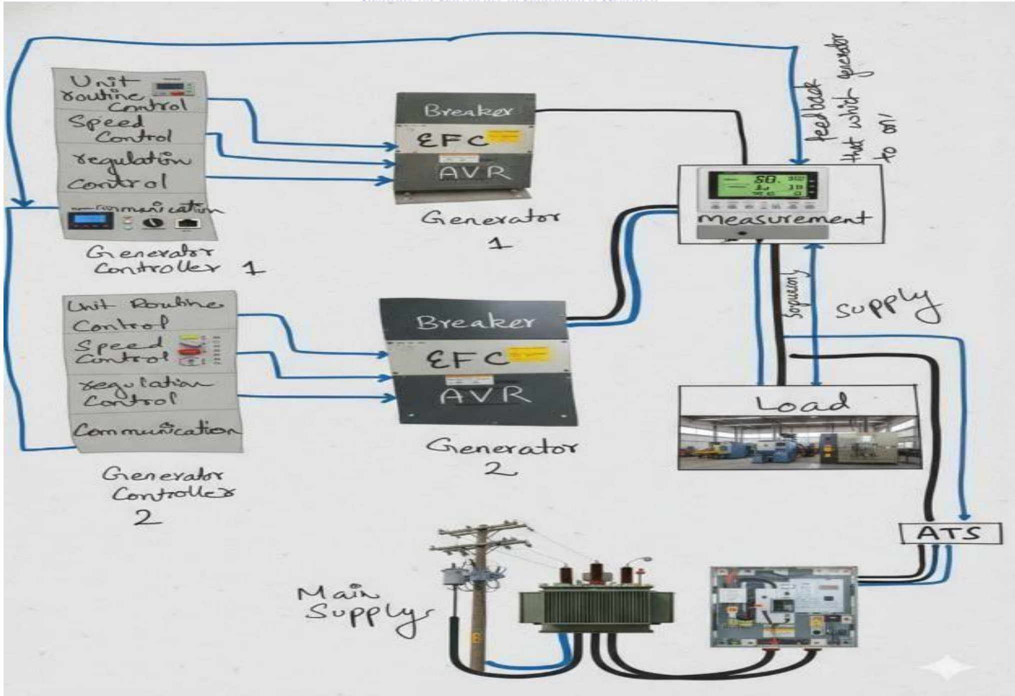


Figure 2e. Generators speed control and magnetic contactor rated 30–60 A, and an overcurrent protection breaker equipped with a 50–150 A trip

2.1.2 The Low-Voltage Auxiliary System: A 60 V to 12 V DC to DC converter electrically isolates the system of the traction loop. It provides electricity to indicators and warning devices. The operator operates the system by a master key switch and an accelerator pedal that has a potentiometer.



3.1 1 Electrical System Overview

The electrical system consists of two identical 1 kW, 50 Hz generators operating in parallel, supported by a coordinated arrangement of switchgear, synchronizing elements, measu-mrement devices, and regulation units. Each generator is equipped with a standard AVR for voltage regulation and manual governor control for power sharing. Protective devices such as MCB/MCCB breakers (rated 10–16 A), CTs, VTs, and load-sharing modules ensure safe and stable operation. A small-capacity copper busbar and appropriately sized
2.5–4 mm2 cables enable the combined power flow (2 kW total) to the load.

3.2 2 System Parameters

Both generators are rated at 1 kW, resulting in a combined output capacity of 2 kW on a 230/240 V single-phase (or 400 V three-phase) system. Each DG delivers a full-load current of approximately 4.35 A (230 V) or
1.45 A (400 V).
Because both generators are equal in power rating, ideal load sharing is 50%–50%, assuming proper droop adjustment. Synchronization tolerances follow standard DG parallel operation limits: voltage deviation
≤ 5%, frequency deviation ≤ 0.2 Hz, and phase angle ≤ 10°. System earthing follows a single neutral-to-earth (N-E) bonding approach with a recommended resistance of ≤ 10 Ω.

3.3 3 Electrical & Energy Calculations

Electrical calculations confirm that each generator delivers a stable 1 kW output under rated conditions, with full-load current computed from fundamental power equations. Under parallel operation, both DGs share the system load equally up to the total 2 kW limit. Voltage and frequency droop characteristics ensure balanced active and reactive power distribution. Practical synchronization parameters and AVR droop values maintain system stability. Results confirm the feasibility of parallel operation at low power levels with predictable performance and safe operating margins.

3.4 Mechanical Components

The mechanical structure supporting each generator includes a 1 kW-class engine, an alternator mounted on a mild steel (MS) skid frame, and anti-vibration mounts that reduce mechanical oscillations during operation. The DG sets utilize air-cooling (typical for small mobile generators), compact fuel tanks (3–5 liters), and standard muffler systems for noise control. Manual throttle control ensures speed regulation, while protective housings provide weather and dust protection. The overall mechanical system is designed to be portable, lightweight, and suitable for mobile field operation.
Current Calculation Breakdown For 1 kW at 230 V (single phase):

$$I = \frac{P}{V} = \frac{1000}{230} = 4.35A$$

For 1 kW at 400 V (3-phase):

$$I = \frac{P}{\sqrt{3} \times V \times pf}$$

Assuming pf = 0.8:

$$I \approx 1.45A$$

Table 1. Electrical & Energy Calculations

Parameter	Formula/Method	Updated Value
Full Load Current (DG1)+ Full Load Current (DG2)	I = P/V and same for DG2	4.35 A (230 V) for both
Total System Capacity	P_total = P1 + P2	2KW
DG1 Load Share + DG2 Load Share	50% for DG1 and 50% for DG2	0.5KW for both
Voltage Regulation	±(5–10)%	AVR - Controlled
Frequency Droop	3–5% manual governor	~1.5–2 Hz drop
Maximum Balanced Load	Until 2 kW total	Both units equal load
Sync Conditions	ΔV ≤ 5%, Δf ≤ 0.2, Δθ ≤ 10°	required

Table 2. Electrical System Components

Component	Specification	Function
DG1+DG2 (Generator 1 and 2)	1 kW, 230/240 V or 400 V, 50 Hz	DG1 (Primary source) DG2 (Secondary source)
Alternators	Single-phase or 3-phase alternators (1 kW)	Power generation
Synchronizer (if used)	Manual sync (lamps) / digital sync-checkV	Verifies match before paralleling
Load Sharing Method	Manual sync (lamps) / digital sync-checkV	Balances load between DGs
AVR	Standard AVR, ±5–10% regulation	Controls generator output voltage
Current Transformers (CT)	5 A secondary, 10–20 A primary (small CTs)	Measurement/protection
Voltage Transformer (VT)	230/400 V input	Voltage sensing
Busbar	20–25 A copper	Combines both generator outputs
Cable	2.5 mm² or 4 mm² copper	DG-to-load connection

4.1 Results and Submission

4.1 Voltage and Current of DG1

waveforms, which remain stable and balanced throughout the simulation, indicating that DG2 maintains proper voltage regulation. Initially, the current The output graph of DG1 shows the behavior of its voltage and current during parallel operation. The upper section represents the three-phase voltage waveforms, which remain steady and balanced throughout the simulation, indicating proper voltage regulation and stable operation. Initially, the current waveforms in the lower section have very low amplitude compared to the voltage, meaning DG1 is running but carrying almost no load. Around the 0.1-second mark, there is a clear change: the current amplitude increases significantly while the voltage stays constant.

This suggests that DG1 was synchronized earlier and then started sharing the load after this point. Before 0.1 seconds, the current looks nearly flat, confirming DG1 was on no-load or very light load. Afterward, the current becomes sinusoidal and aligned with the voltage, showing active power delivery. The waveforms remain symmetrical and distortion-free, which indicates healthy three-phase operation and proper control. The sudden rise in current likely corresponds to load sharing adjustment when DG2 comes online. Overall, DG1 transitions smoothly from idle to active load sharing, which is typical in parallel generator setups.

4.2 Voltage and Currentof DG2

The second output graph shows the voltage and current behavior of DG2 during parallel operation. The upper section represents the three-phase voltage waveforms in the lower section have very low amplitude, meaning DG2 is running but not supplying significant load at the start. Around the 0.1-second mark, there is a noticeable increase in current amplitude while the voltage stays constant, which suggests DG2 begins to share the load after synchronization. Before this point, DG2 was practically on no-load or very light load, as seen from the nearly flat current waveforms.

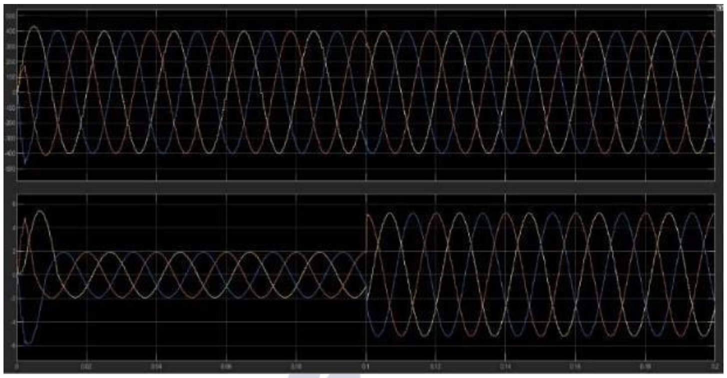


Figure 4.1

After 0.1 seconds, the current becomes sinusoidal and aligned with the voltage, showing that DG2 is actively delivering power to the system. The waveforms remain symmetrical and distortion-free, confirming healthy three-phase operation and proper control. This smooth transition indicates that DG2 successfully synchronized and started contributing to load sharing without instability. Overall, DG2 moves from idle to active participation in parallel operation, complementing DG1 for balanced power supply.

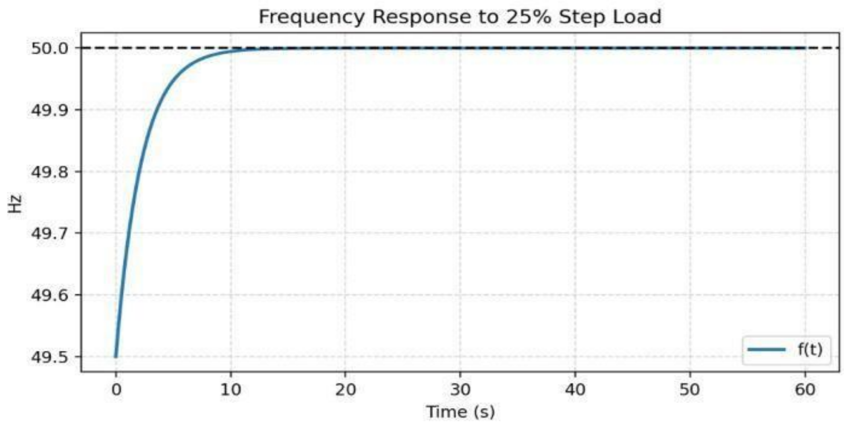


Figure 4.2

4.3 3 Frequency of DG1 and DG2

The third output graph shows the frequency response of DG1 and DG2 during parallel operation. Both graphs indicate that the generators start close to the nominal frequency of 50 Hz. Initially, there is a noticeable overshoot where the frequency rises above 50 Hz, reaching around 50.04 Hz, which happens during synchronization and load adjustment. After this peak, the frequency drops slightly below 50 Hz, indicating a transient response as the system stabilizes.

Following this, small oscillations occur between 49.98 Hz and 50.02 Hz, showing that the generators are adjusting to share the load and maintain system stability. These oscillations gradually dampen over time, and by the end of the graph, the frequency settles close to 50 Hz for both DG1 and DG2. This behavior is typical in parallel operation, where initial fluctuations occur due to governor action and load sharing dynamics, but the system eventually reaches a stable state. Overall, the frequency response confirms that both generators successfully synchronized and stabilized without major deviations, ensuring reliable operation.

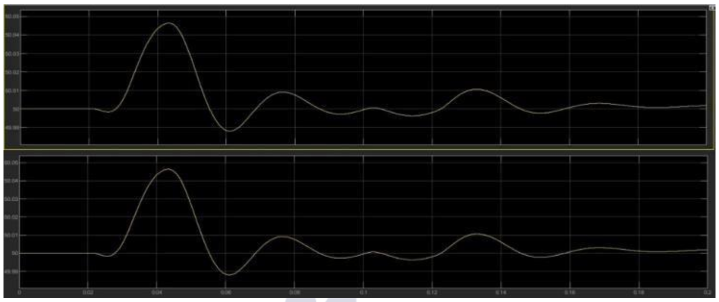


Figure 4.3

4.4 Active and Reactive power of DG1 and DG2

This figure shows the active (P) and reactive (Q) power of DG1 and DG2 during synchronization and load sharing. At startup, both units exhibit a brief transient/overshoot as the governors and AVRs settle. From 0 to about 0.1 s, the powers remain low—both generators are running near no-load. Around 0.1 s there's a clear step: P and Q jump upward, indicating the load is picked up after successful paralleling. After the step, DG2 stabilizes at a higher active-power level than DG1, suggesting it is the larger-rated set or has a higher kW droop reference. DG1 settles at a lower but steady kW, consistent with proportional load sharing Reactive power for both machines also increases and holds nearly constant, showing AVR droop is sharing vars properly. A slight post-step drift/mini ripple reflects droop action and damping as the controllers equalize kW and kVAr. There are no sustained oscillations, power reversals, or hunting, so neither unit is motoring nor over-excited. Overall, the plot confirms smooth load pickup, proportional kW sharing by rating, and coordinated kVAr sharing with stable operation.

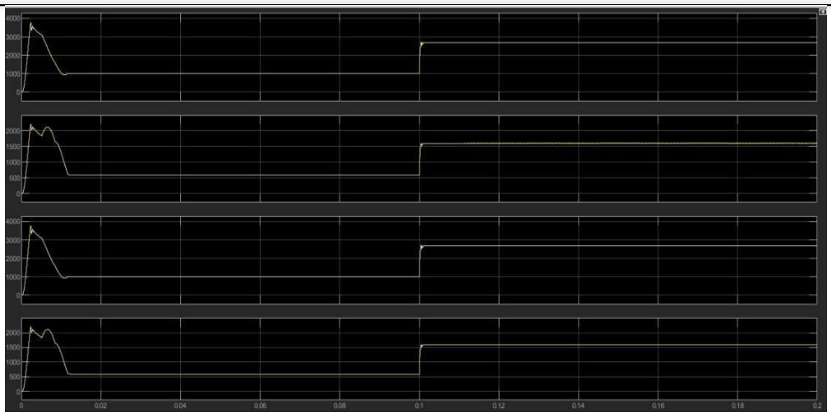


Figure 4.4

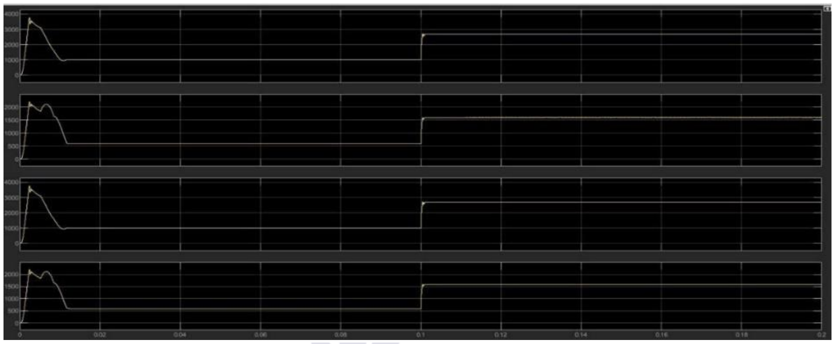


Figure 4.5

5.1 Conclusion and Future Scope

By engineering synchronization, droop sharing, secondary restoration, protection, and grounding as an integrated system, two differently rated mobile DGs can be paralleled safely and effectively. Parallel operation of two differently rated mobile DGs is practical and robust when the system is engineered with proper synchronization hardware and permissives, Droop-based primary control with equal per-unit slopes to achieve proportional kW/kVAr sharing, Optional secondary control for restoring nominal V and f without disturbing sharing. This methodology delivers a scalable, reliable temporary power plant suitable for construction sites, events, mining, telecom, and disaster recovery—

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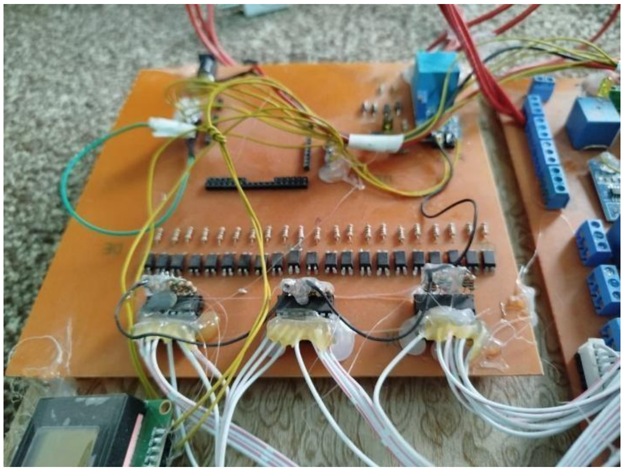
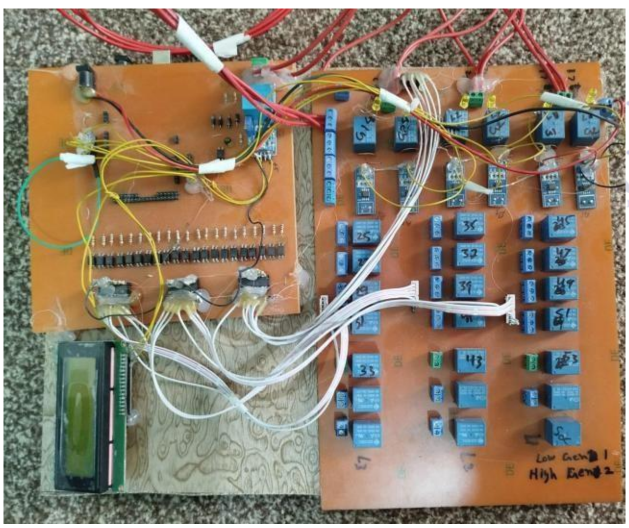
while ensuring the smaller unit is protected and the larger unit is utilized efficiently.

5.2 Hardware Implementation





Results

When Dg 1 is On

When Dg 2 is On

When both Dg's is on

5.3 Future Scope

This methodology delivers a scalable, reliable temporary power plant suitable for construction sites, events, mining, telecom, and disaster recovery—while ensuring the smaller unit is protected and the larger unit isutilized efficiently. For emergency/standby applications, load sharing controls (both kW and kVAR) should all be of the same manufacturer and model. Droop control may be suitable for some prime power applications and isolated bus kVAR load sharing.

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