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# DISTRIBUTED UPS SYSTEMS AND THEIR CONTROL ISSUES

**ABSTRACT**

In this study, it has been investigated distributed power systems and their control strategies. These systems consist of some uninterruptible power supplies (UPS) units which operate in parallel. If there is some fault with these units, it can be obtained continuous power flow, since the other units will continue to deliver power. In this article it is discussed especially load-frequency control and we offer an implementation using a simulation.

**Keywords:** Distributed Power System, Distributed Operation, Parallel Operation of Inverters or UPSs, Load Sharing, Load-Frequency Droop Method

# DAĞITILMIŞ KGK SİSTEMLERİ VE ONLARIN KONTROL KONULARI

**ÖZET**

Bu makalede, dağıtılmış sistemleri ve bunların kontrol stratejileri incelenmiştir. Bu sistemler paralel çalışan kesintisiz güç kaynağı (KGK) ünitelerinden oluşmuştur. Bu sistemdeki ünitelerden bir veya birkaçında oluşabilecek arıza durumunda, diğer üniteler güç akışını devam ettireceğinden, sürekli bir güç akışı sağlanmış olur. Makalede yük-frekans düşüm yöntemi üzerinde ayrıca durularak, bu yöntemin uygulanması bir benzetim örneğiyle gösterilmiştir.

**Anahtar Kelimeler:** Dağıtılmış Güç Sistemi, Dağıtılmış Çalışma, Evirici veya KGK'ların Paralel Çalışması, Yük Paylaşımı, Yük-Frekans Düşüm Yöntemi

## 1. INTRODUCTION (GİRİŞ)

UPS systems operate, traditionally in conjunction with the main power system, to ensure a continuous power supply for sensitive and critical ac loads. The load power is drawn from the mains when it is available [1]. When the mains fail, the load power is transferred to the UPS unit. This unit of backup energy is typically a battery bank [1 and 2].

For sensitive and critical loads, it is imperative that the transfer from mains to UPS system take place without any break in the load power. In these cases, the UPS system operates in the hot standby mode. It is always connected to the load, and is operational at all times.

An important challenge arises from the fact that the units are not under one roof, but distributed. The control of the system under at this condition is difficult. Application of different control techniques becomes necessary if there is no communication between the units [3 and 4].

In this paper firstly it is explained interconnected network system which consists of the distributed UPS units and its different control schemes. After, power-frequency droop method is investigated in detail. Finally, it is given a simulation related to this method.

## 2. PARALLEL OPERATED POWER SUPPLIES (PARALEL ÇALIŞAN GÜÇ KAYNAKLARI)

This section presents some applications that make use of parallel operated power supply systems. In this context, the emphasis is on applications which involve some aspects of distributed UPS operation, most notably, parallel operation. This section serves to emphasize the current trend toward a distributed nature for power supplies in critical applications.

### 2.1. AC Systems (AA Sistemleri)

A major usage area of parallel operating power supplies in the evolution of telecommunications power supply architecture. In essence, this system is built up of up to multiple inverter units, thus achieving a maximum rating of individual unit. Starting with a single unit for low installed load, the system is capable of being expanded to total of units rating and as new loads are installed, thus providing a degree of flexibility for load expansion. Similarly to the inverter units, the battery and the charger have a built-in modularity. Figure 1 shows a schematic diagram a sample of the distributed AC system [5].

While this system uses parallel connection of the modules, all the modules are housed in the same cabinet, and so is not a truly distributed system. Moreover, there is transfer of information between the systems for the purpose of synchronization.

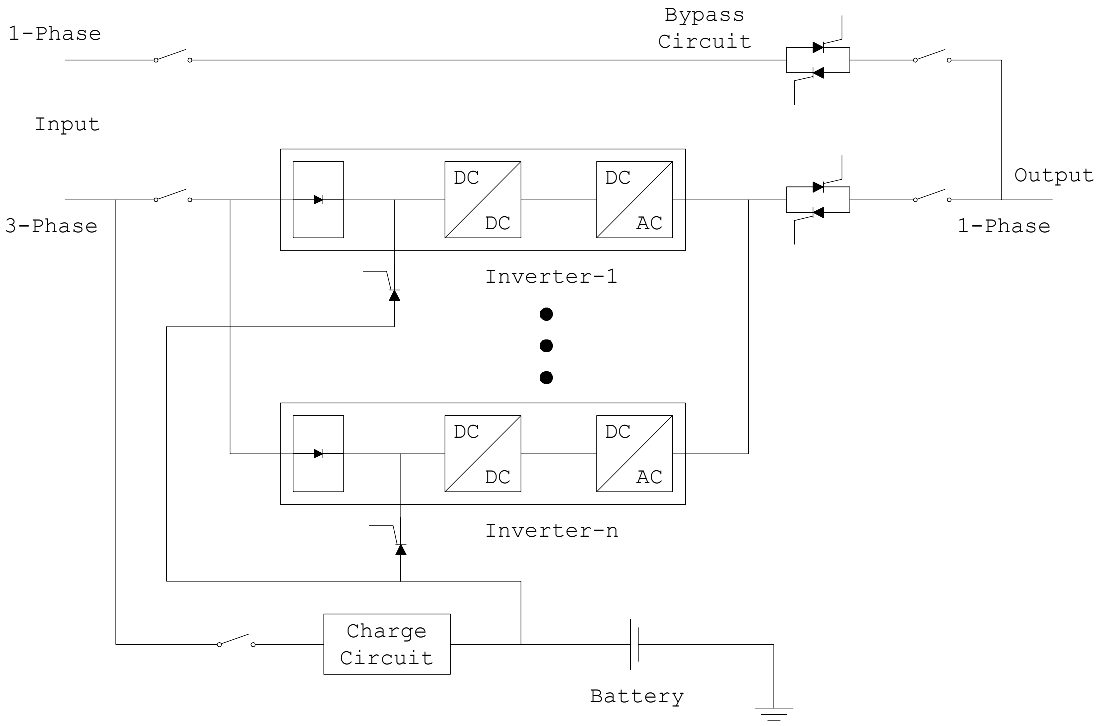


Figure 1. Modular UPS system at telecommunications power supply system
(Şekil 1. Telekominikasyon güç sistemlerindeki modüler KGK sistemi)

### 2.2. DC Systems (DA Sistemleri)

There has been a considerable amount of literature in recent years in the use of distributed dc power supplies, made up of low power modules (50W to 200W), for telecommunication equipment. Because some of the motivations for distributed dc power systems are the same as for their ac counterparts, this section takes a brief look at the present trend in dc distributed power supplies also. DC distributed power system shown in Figure 2 [5].

If a fault occurs in a section of the network, that section can be isolated without affecting the functioning of the rest of the network.

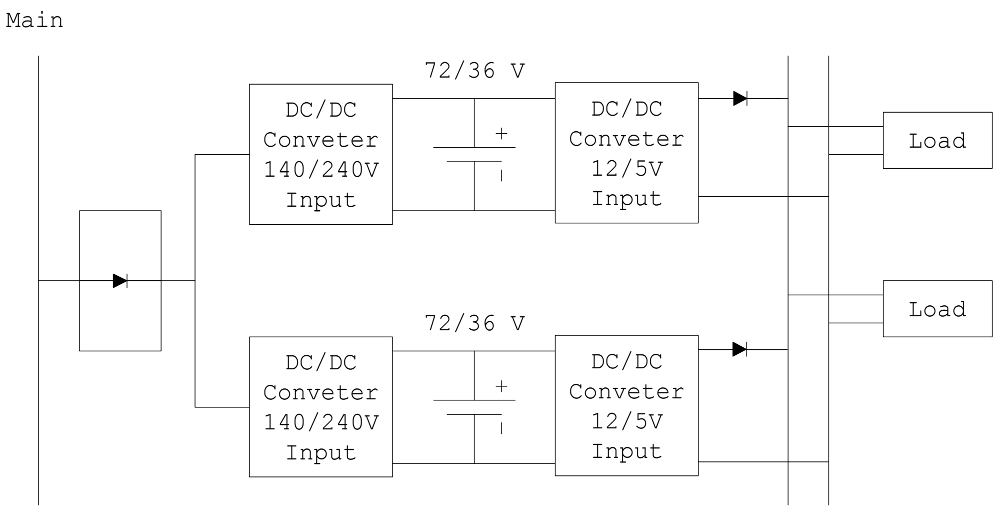


Figure 2. DC distributed power system.
(Şekil 2. DA dağıtılmış güç sistemi)

**3. DISTRIBUTED UPS SYSTEM (DAĞITILMIŞ KGK SİSTEMİ)**

A distributed network of multiple units of distributed UPS units enhances the provision of continuous power to sensitive and critical loads. The parallel operation and redundancy is the location of UPS units flexibly in an interconnected `secure network'. The structure of secure network is shown in Figure 3. Such an interconnected network of UPS units is termed a distributed UPS system', and forms the central subject of the present work.

At the present time, parallel UPS operation is confined to parallel operation of units that are located near each other. This permits the exchange of control information between the units for the purpose of parallel operation. In contrast, our concern here is with truly distributed operation, where the units and also the loads are located flexibly on a distribution network. Figure 3 shows the system structure that can support these operations [6].

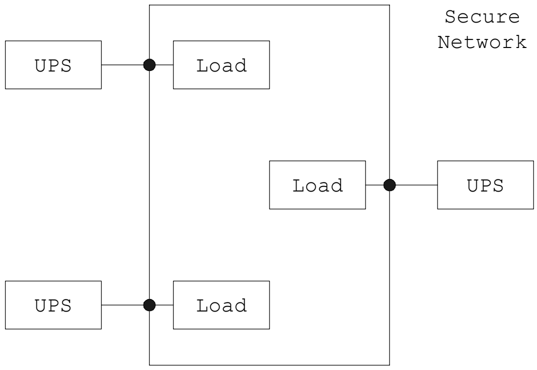


Figure 3. Shape of secure network consists of distributed UPS units
(Şekil 3. Dağıtılmış KGK uinitelerini içeren güvenli şebekenin yapısı)

In a distributed UPS system, UPS units are located flexibly in an interconnected secure network, like an interconnected power system. The advantages of UPS interconnection include:

- Enhanced reliability of power supply to critical loads by the addition of redundancy.
- Increased total power available on the secure bus during mains failure.
- Ease of future expansion of the critical load bus.
- Flexible routing of power between UPS units and critical loads.
- Ability to regulate voltage at distributed points on the secure network.
- Faster transient response following load changes.

It may not be too far amiss to state that the present situation of distributed UPS systems is in some sense similar to the state of electric power generation, distribution and utilization in the early days of the power system industry. The earliest instances of the use of electrical energy were of single generators feeding local loads. As demand increased, generators were connected in parallel to feed the increased load, and the first stability concerns appeared. The concerns were not very acute at this point, because of the close location of the generators and the loads. However, with increasing demand, it became necessary to transmit electric power over large distances, and successful efforts were made to address the increased stability problems.

Power system complexity increased still further when increasing demand made it essential to interconnect power stations in order to supply the load. This trend toward interconnected systems has continued to the present, when entire areas are interconnected due to reasons of power supply reliability and economics.

In the case of interconnected UPS systems, the expected proliferation of sensitive and critical loads in the very near future will make the use of truly distributed UPS systems essential. To a great extent, this proliferation is already apparent in the use of critical loads such as medical equipment, air and ground traffic control systems, electronic data processing systems, wireless communication equipment, and process plant instrumentation. There is therefore a need to identify and address the issues concerning the configurations and control of truly distributed UPS systems.

## 4. UPS CONTROL ISSUES (KGK DENETİM KONULARI)

In his section, we consider the control issues relevant to distributed UPS operation. The emphasis of this review will be on those aspects of the control system which are concerned with parallel operation. The review of UPS system architectures in the previous section brought out the fact that while there existing multi-unit UPS systems in which UPS units are operated in parallel for the sake of modularity, power rating, and redundancy, these systems are not distributed in the true sense. That is, these systems deal with the parallel operation of units which are closely spaced, and the following review will reject this fact. It will be seen that the controllers for these systems make considerable use of data communication between the parallel units for the purpose of synchronization, power sharing, and mode detection. Given the spatial separation of the units, data communication is not desirable in a truly distributed system.

A good review of the issues regarding parallel operation of voltage source inverters (VSI) is given in [7], involving both, inverter power circuit and control issues. Since many existing controllers for parallel VSI operation employ schemes related to those reviewed in [7], it is worth discussing them in some detail here. To begin with, the control of an inverter operating in parallel with the utility line presents few difficulties in principle, since the output voltage and frequency are already established by the utility. In this case, the inverter typically has set-points for its output real power P and the reactive power Q.

### 4.1. Parallel Operation by Power Deviation Control (Güç Sapması Denetimiyle Paralel Çalışma)

In this control method, the inverter controllers act to divide the total load active power P and the total load reactive power Q equally among the n parallel connected inverters. To this end, the total load current $I_L$ is measured, and scaled by 1/n. The scaled current is made available to each inverter controller. The controller uses this scaled feedback to compute the real and reactive components of the current that it should put out, and compares these with the current that it actually puts out. It then changes its output voltage magnitude and frequency to make the actual current equal to the computed current.

Note that this scheme requires that the inverter current deviations are measurable. This requires either that the total load current is measurable, or that the actual current of each inverter is made available to every other inverter by some means. Both points imply the use of communication. Further, the first point implies that the load is concentrated, so that the total load current can be measured. This is in direct opposition to the premise of distributed systems.

### 4.2. Master-Slave Control (Master-Slave Kontrol)

In the sense of measuring and transmitting the total load current to the individual unit controllers for the sake of parallel operation, [8] uses a similar philosophy to achieve load sharing control. A schematic diagram of the control scheme of [8] is reproduced in Figure 4.

The overall control structure of Figure 4 has three separate controllers: one each for the two inverter units, and one master controller. The two unit controllers control the output voltage of the two units, while one of the tasks of the master controller is to ensure load sharing. To this end, it provides the desired output current information, $I_0$=2, to the unit controllers, which modify their voltage reference outputs to achieve the desired parallel operation.

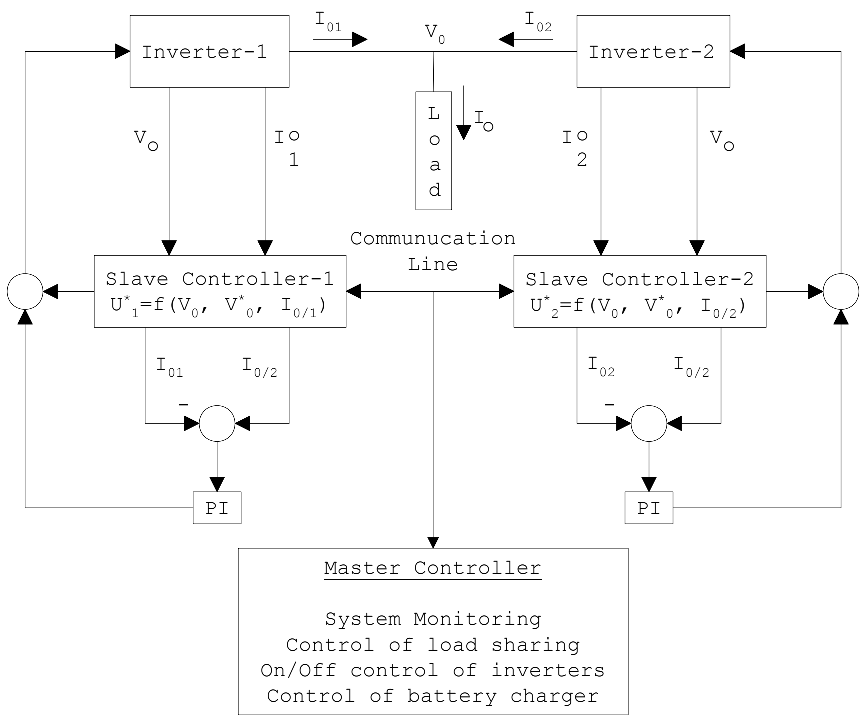


Figure 4. Master-Slave control schema.
(Şekil 4. Master-Slave denetim şeması)

### 4.3. Parallel Operation by Frequency and Voltage Droop Methods (Frekans ve Gerilim Düşüm Yöntemleriyle Paralel Çalışma)

This scheme is directly patterned on the use of droops in the control of interconnected electric power systems [9, 10 and 11]. In this method, the inverter output voltages and currents are measured by the controller and from these, the output real power P and reactive power Q are calculated. The inverter frequency is made to drop slightly with increasing P, and increase slightly with decreasing P. Similarly, the inverter output voltage magnitude is made to drop slightly with increasing Q, and increase slightly with decreasing Q. This is shown schematically in Figure 5. The droop method for parallel operation has been in use for many years in the electric power system industry. The main advantage of this method is that it does not make any use of communication, and does not need information about the total system load.

An example of a comprehensive control scheme for the control of parallel-connected inverters in stand-alone systems is to be found in [6]. In this scheme, the droop method is used to achieve parallel operation without communication between the inverters, and fast inner control loops are used for rapid control of the three-phase output voltage to maintain a sinusoidal wave shape in the face of arbitrarily changing loads.

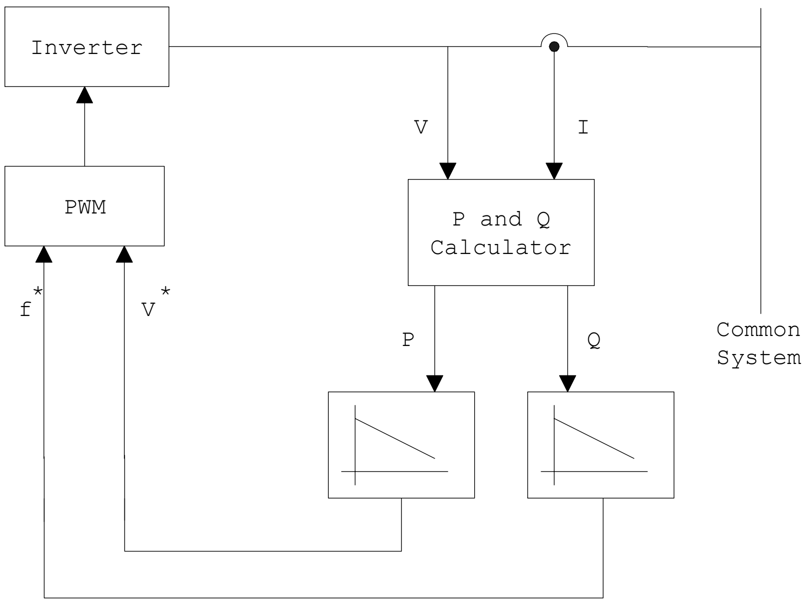


Figure 5. Load-frequency droop method
(Şekil 5. Yük-frekans düşüm yöntemi)

Figure 6 shows the frequency deviation in response to power variation of the inverter. The variation is defined as

$$\omega_1 = \omega_0 - b(P_0 - P_1) \quad (1)$$

Where "-b" is the slope of the line, $P_0$ is the power at the speed $\omega_0$, and $P_1$ is the power at the speed $\omega_1$. In order to share the total load proportionally, following selection of the slopes becomes necessary:

$$b_1 P_{01} = b_2 P_{02} = \ldots = b_n P_{0n} \quad (2)$$

Where $P_{01}$, $P_{02}$,…,$P_{0n}$ represent the powers of the unit 1, unit 2,... unit n.

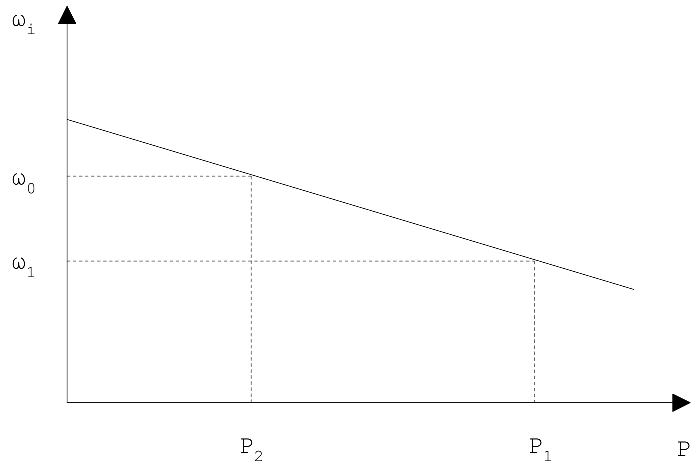


Figure 6. Load-frequency droop characteristic
(Şekil 6. Yük-frekans düşüm karakteristiği)

Deviated frequency that it is resulting of power-frequency droop is brought back to its nominal value by using frequency restoration algorithm. Frequency restoration with correct power sharing can be achieved by shifting the droop characteristic in the vertical direction. The shift should be proportional to the inverter power rating. The process is depicted in Figure 7. The desired frequency restoration is maintained during the load sharing process [12].

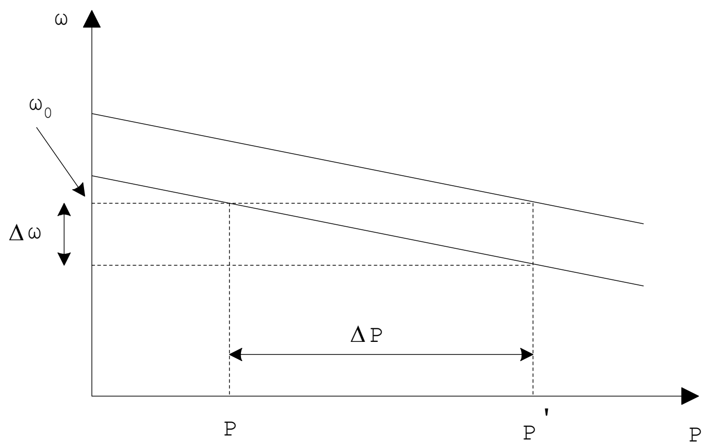


Figure 7. Frequency restoration
(Şekil 7. Frekans düzenleme)

## 5. AN EXAMPLE FOR PARALLEL OPERATION BY USING DROOP METHOD (DÜŞÜM YÖNTEMİ KULLANILARAK PARALEL ÇALIŞMA İÇİN BİR ÖRNEK)

Figure 8 shows one phase of two three-phase inverters operating in parallel. The line connecting the two outputs has an inductance of "L". $V_1$ and $V_2$ represent the filter output voltages. Depending on the inverter ratings and load values, there may be a power flow through the tie-line between the inverters.

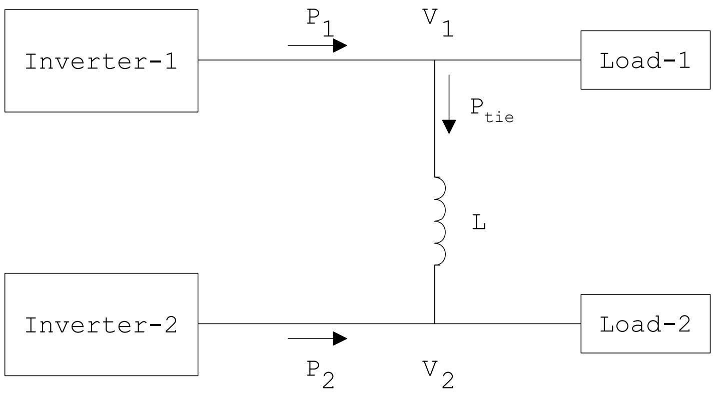


Figure 8. Connection diagram of distributed inverters operating in parallel.
(Şekil 8. Dağıtılmış paralel eviricilerin bağlantı şekli)

The power of the tie-line is expressed as follows:

$$P = \frac{3V_1V_2}{2\omega L}\sin\delta \qquad (3)$$

Equation (3) shows that the active power is proportional with sin(δ). δ is the angle between the phasors $V_1$ and $V_2$

This simulation has been implemented by MATLAB-Simulink package program and solution method is taken ODE23tb and 1e-4 maximum step size.

A 64.5Ω resistor has been used as load for both inverters. It is assumed, the rated power of inverter 1 is twice that of inverter 2.

Initially, both loads draw 750W, and the total load is 1500W. Inverter 1 supplies 1000W, and inverter 2 supplies the remaining 500W. This requires 250W power flows through the tie-line from inverter 1 towards inverter 2. At this situation, $V_1$ phasor leads $V_2$.

At the 1 sec. instant, the load nearby inverter 1 is increased to 1500W, changing the total load to 2250W. As the load is increased, the frequency of inverter 1 is reduced, and this results in a smaller phase angle between phasors $V_1$ and $V_2$. This, in turn, reduces the power flow through the tie-line. As expected, at the steady state inverter 1 should supply 1500W, and inverter 2 should supply the remaining 750W. These values are equal to the loads nearby each inverter, and no power flow occurs through the tie-line.

Figure 9 shows the power supplied by each inverter. Load sharing between the inverters is as expected proportional to the power ratings. This figure plotted additionally zoomed in 1-2 sec. time range.

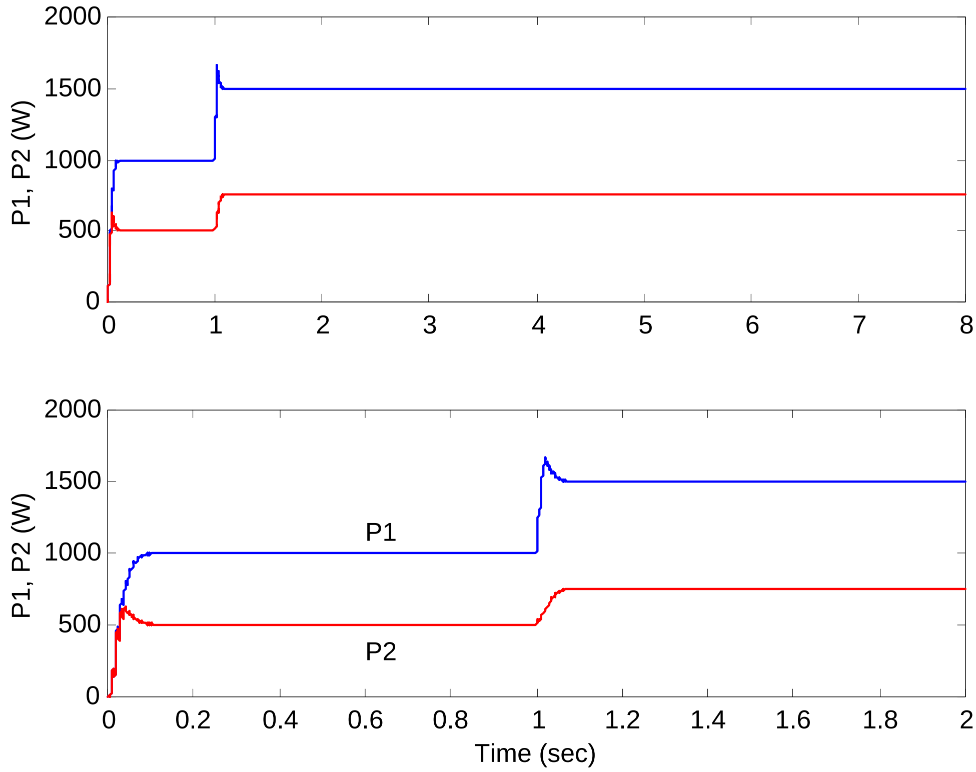


Figure 9. Power supplied by each inverter ($P_1$, $P_2$)
(Şekil 9. Her bir evirici tarafından sağlanan güç ($P_1$, $P_2$))

Figure 10 shows the inverters frequency variations. The loads are initially the same for each inverter. As the rated power of inverter 2 is lower, the frequency deviation for this inverter is higher. Frequencies of the two inverters are brought to an equal value by the effect of load-frequency characteristic. As the load increase at 1 sec. occurs near inverter 1, this inverter responds first and its frequency drop is higher. Then, the second inverter starts to support the load and its frequency also drops. After the load sharing transient is over, inverter frequencies are restored to the original value.

This figure also shows difference of frequencies. When any load chance in system, in order to provide load sharing between inverters, frequencies must be chancing. When load sharing is completed frequencies are taken same value.

Frequency restoration continues along with the load sharing period. As seen from Figure 10, it approaches the rated value during the transient. In steady station, frequencies are brought back to its nominal value. Since better appearance this figure also plotted in 1-2 sec. time range.

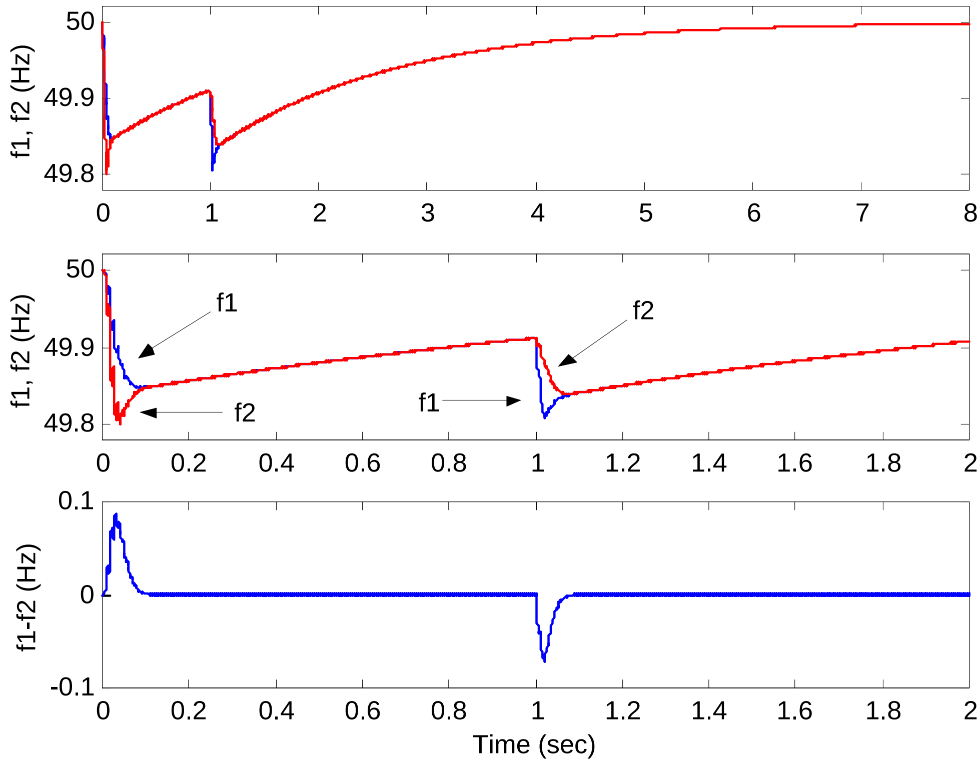


Figure 10. Output frequency of each inverter ($f_1$, $f_2$)
(Şekil 10. Her bir eviricinin çıkış frekansı ($f_1$, $f_2$))

## 6. CONCLUSION (SONUÇLAR)

This paper has attempted to bring into perspective the design and control issues relating to distributed UPS system. In there, UPS control issues are overviewed and especially emphasize load-frequency droop method. Load-frequency droop method provides load sharing among with their power ratings of UPS that they may have different rating UPS. Frequency restoration operates with this method is brought the deviated frequency to its nominal value.

In distributed UPS system, the UPS units and sensitive and critical loads are located flexibility round an interconnected power distribution network. In this respect, the topology of a distributed UPS system is similar to that of an interconnected power system. The distributed UPS systems to supply enhance power rating of system, redundancy and reliability. Thus it can be achieved more sensitive and critical loads feeding.

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