Combination Voltage-Controlled and Current-Controlled PWM Inverters for UPS Parallel Operation

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Abstract— **In this paper the scheme of combination Voltage-Controlled and Current-Controlled PWM inverters for parallel operation of single-phase uninterruptible power supply (UPS) is proposed. The Voltage-Controlled PWM Inverter (VCPI) unit as a master is developed to keep a constant sinusoidal wave output voltage. The Current-Controlled PWM Inverter (CCPI) units are operated as slave controlled to track the distributive current. The power distribution center (PDC) performs the function of distributing the output current of each active unit. In this proposed scheme of parallel operation, each of the units can be designed nearly independent, and the CCPI units do not need a PLL circuit for synchronization. As a result, the parallel operation of UPS is easy to implement and to expand system capacity. For the purpose of illustration, the system, including three single-phase units which operate in parallel, is analyzed and experimental results are given.**

I. Introduction

UNINTERRUPTIBLE power supply (UPS) systems have been widely used for critical loads such as computer systems, instrumentation plants, communication systems, and hospital equipment to supply constant voltage and constant frequency power [1], [2]. With the rapid advances of the information society, UPS's are becoming ubiquitous in supplying ever increasing critical loads. For expanding system capacity, either a large UPS unit or a multi-unit modular system operated in parallel connection is conceivable. The former approach may not be practical because of high initial cost, site installation difficulties, (e.g., size, weight, system reliability, [e.g., single point of failure.]) By contrast, the latter approach facilitates system expansion and redundancy. The method of parallel operation to increase the UPS rated capacity is implemented by synchronizing each of the units of output voltage frequency and utilizing their voltage magnitude and phase angle through a series inductor to control the power distribution of each unit [3]–[8].

The function of synchronization is performed by a PLL circuit [9]. The PLL circuit is adopted to control the phase angle among the inverters and ac power source. It is difficult to obtain a fast response of power distribution control because of the inherently slow response of the PLL circuit. Also, when the parallel units are different in output voltage, resultant circulating current can result in malfunction and destruction of the UPS system. This is especially so if the load is light [10]. Thus, the above scheme of parallel operation is difficult to implement and to provide for expansion of system.

The types of PWM inverters considered are Voltage-Controlled (VCPI) or Current-Controlled (CCPI) with voltage source [11]. The scheme of parallel operation combining VCPI and CCPI is proposed in this paper. The parallel system consists of a single master VCPI unit, n sets of slave CCPI units, and a power distribution center (PDC) [12]. The VCPI, as the master, is controlled to provide a constant sinusoidal wave output voltage, and the CCPI's, as slaves, are controlled to monitor the reference current which is distributed from the PDC. The current control loop of the CCPI contains output voltage feedforward to avoid output voltage disturbance and reference current feedforward for fast current response. The CCPI can closely track the reference current obtained from the load current through the PDC. Since the reference current follows the load current, the CCPI can track the load current at the voltage output frequency which is controlled by the VCPI; therefore, the CCPI units do not require PLL circuits for the synchronized operation. Thus, the CCPI provides a means for easy expansion of this type of parallel UPS system.

For increasing overall system efficiency of UPS operation, the outputs of parallel CCPI units are determined by the load power requirements and the quality of the utility system, faulty or not, which establishes the battery capacities of the units. Each of the active units that distribute output power and the distributive output power of each active unit depends on the rated capacity of the active units. The PDC performs the function of distributing the output power of each unit. The proposed method for combination of the VCPI and CCPI's for parallel operation of UPS's is simple to implement, and provides the flexibility to expand system capacity. Three single-phase units (one VCPI and two CCPI's) are used to experimentally verify parallel system operation. They all have a full bridge inverter, using IGBT's as switches.

II. Configuration

Fig. 1 shows the basic diagram for parallel operation of a UPS combination with a VCPI and n CCPI's. This includes 1) one VCPI unit as a master, which provides a constant voltage, constant frequency output; 2) n CCPI units as slaves, which track the current reference distributed by the power distribution center; and 3) the PDC. With this scheme, the VCPI can be

Manuscript received March 18, 1993; revised April 12, 1995.

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IEEE Log Number 9413546.