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3상 오프라인 무정전 전원 시스템의 돌입전류 제거

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Inrush Current Elimination for a Three-Phase Off-Line UPS System

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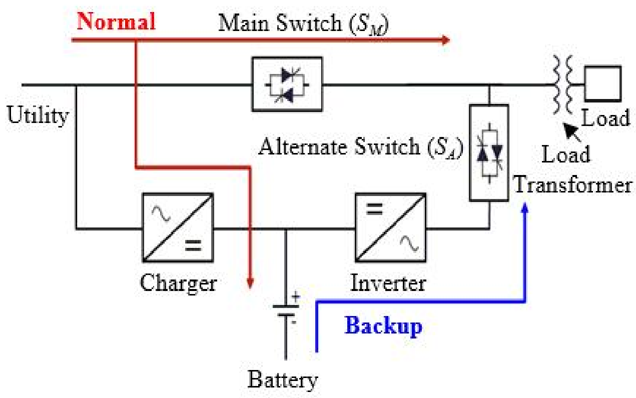
Abstract - Many sensitive loads always rely on UPS systems to maintain continuous power during abnormal utility power conditions. As any disturbance occurs at the utility side, an off-line UPS system takes over the load within a quarter cycle to avoid a blackout. However, the starting of the inverter can root the momentous inrush current for the transformer installed before the load, due to its magnetic saturation. The consequences of this current can be a reduction of line voltage and tripping of protective devices of the UPS system. Furthermore, it can also damage the transformer and decrease its lifetime by increasing the mechanical stresses on its windings. To prevent the inrush current, and to avoid its disruptive effects, this paper proposes an off-line UPS system that eliminates the inrush current phenomenon while powering the transformer coupled loads, using a current regulated voltage source inverter (CRVSI) instead of a typical voltage source inverter (VSI). Simulations have been performed to validate the operation of proposed off-line UPS system.

1. Introduction

The quality and consistency of electric power is a major concern for domestic, commercial and industrial consumers these days. Sudden voltage sags, swells, and outages over and over again disturb the operational processes and even lead to equipment damage [1]-[2]. For the uninterrupted operation of critical applications, an off-line UPS system is usually installed to uphold the power during any abnormal utility power condition. An off-line UPS topology is sometimes referred as a line-preferred UPS system. In general, it consists of a main switch to connect the load directly to the utility, a battery that can be charged through any of the charging mechanisms (i.e., rectifier/charger), an inverter to feed the load from the backup power of the battery during abnormal utility condition and an alternate switch to connect the load to the inverter of the UPS system [3]. The major advantages of an off-line UPS are the high efficiency, small size, simple design, and low cost. Besides several advantages, some of the negatives associated with this topology are the absence of isolation of load from the utility and the power supplied to the load is not regulated, hence the load is not protected from any of the transient occurrence at the utility side [4]. To overcome this and to provide isolation for the loads from the utility, a load transformer is generally installed between the loads and the utility. However, during the transition of load from the utility to the inverter (which takes 4msec in most of the cases), a flux offset is usually established for the load transformer which was installed before, for the electrical isolation or voltage matching purpose. Hence, when the UPS takes over the load, the transformer flux may be driven beyond the saturation threshold and causes magnetic saturation. This saturation of load transformer in result generates the serious magnitude of inrush current [5]. Generally, the magnitude of inrush current might range from 2-6 times the rated load current depending upon numerous factors including the magnetic properties of the load transformer [6]. The inrush current may result in reduced line voltage, activate the over-current protection of the UPS system and damage the sensitive load. Furthermore, it can also damage the transformer and decrease its lifetime by increasing the mechanical stresses on its windings [7].

Numerous solutions can be used for the inrush current mitigation of the transformer associated with an off-line UPS system. as, by decreasing the output voltage upon identifying the magnitude of the inrush current [8] or by introducing the inverter voltage at appropriate phase angles can reduce the inrush current phenomenon [9] but it can cause an interruption for a longer time than the conventional off-line UPS topology. Introducing the resistors or reactors during the starting time of the UPS system can reduce the inrush current magnitude as well, but to accommodate these resistors, reactors, and electromechanical switches, a large power distribution panel is required [10].

To eliminate the inrush current phenomenon during the transition of load while powering the load transformer, this paper proposes an off-line UPS system using a standard current regulated voltage source inverter (CRVSI), which utilizes a current control strategy implemented in stationary frame of reference.



<Fig. 1> Basic diagram of an off-line UPS system.

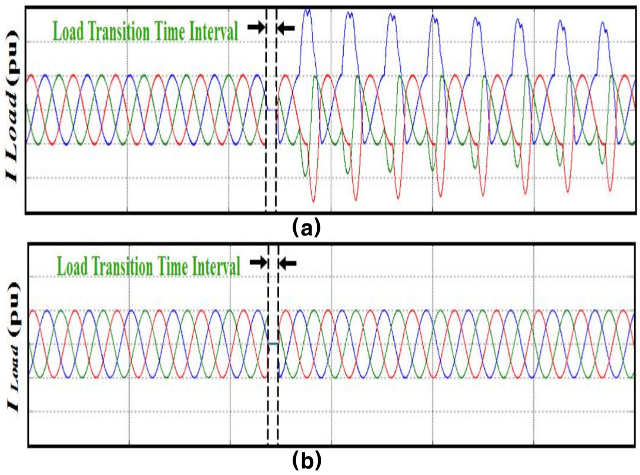
2. Operational Principle and Simulation Results

To investigate the behaviour of the proposed off-line UPS system, a system as shown in Figure. 1 has been used for the simulations. The simulations have been performed through MATLAB/SIMULINK and the system parameters are given as follows:

- Supply/Grid: 220V, 60 Hz;
- UPS system inverter: Output voltage 220V, 60 Hz, switching frequency is 20 kHz. DC bus voltage 365 V.
- Load Transformer: 1.0 kVA, 220/220 V (Δ-Y);

- Load: 500 VA passive load, operating at 220 V;
- Filter: LC output filter is used at the inverter output. The filter inductance (L_f) is 20 mH and the capacitance (C_f) is 10μF;

During normal operation the load is supplied current from the utility through main switch. However, as any fault or disturbance occurs at the utility side, the main switch gets opened and the alternate switch gets energized to connect the load to the inverter to avoid any blackout. This transition of load takes a quarter cycle depending upon the fault detection and transition mechanism adopted for the UPS system. During this load transition time interval, a dc offset is usually established and the flux of load transformer installed before the load can be driven beyond its saturation level resulting in serious magnitude of inrush currents. Fig. 2(a) shows the load current for the conventional off-line UPS system during such a condition. From the figure it is evident that, as the load transition takes place, the load currents increases and attains a magnitude of 3 (p.u), which is around three times the rated load current. The operation of the proposed UPS system is same as the conventional off-line UPS system. However, the proposed UPS system uses a current regulated voltage source inverter (CRVSI), instead of the conventional voltage source inverter (VSI). The inverter utilizes a current control algorithm implemented in stationary frame of reference. This enables the inverter to keep the load current constant and never let it exceed, from prescribed value during the transition of load. Fig. 2(b) shows the load current for the proposed off-line UPS system. From the figure, it can be observed that the load current remains constant I.e., 1 (p.u) before and after the load transition time interval.



<Fig. 2> Load current for (a) conventional (b) proposed off-line UPS systems (X-axis: 40 msec/div, Y-axis: 1.0 (pu)/div).

3. Conclusion

The problems associated with the generation of inrush current when using an off-line UPS system while powering a load transformer, have been discussed in this paper. It is demonstrated that by using a current regulated voltage source inverter (CRVSI) instead of the conventional PWM voltage source inverter (VSI) for an off-line UPS system, the phenomenon of inrush current can be eliminated. Simulations for the conventional and proposed UPS systems were performed.

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