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Parallel distribution transformer loss reductions: A proposed method and experimental validation

David Borge-Diez [1], Antonio Colmenar-Santos *, Manuel Castro-Gil [1], José Carpio-Ibáñez [1]

Departamento de Ingeniería Eléctrica, Electrónica y de Control, UNED, Juan del Rosal, 12 – Ciudad Universitaria, 28040 Madrid, Spain

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ABSTRACT

Transformers in electrical distribution systems for buildings and industries are set up to ensure the continuity of supply. Modern distribution transformers are reaching increasingly higher levels of energy efficiency but contribute to between 16% and 40% of the energy losses associated with electrical distribution systems. This paper examines and proposes a method to reduce losses in transformation systems and thus to reduce the associated emission of greenhouse gases (GHGs). This paper proposes a method of system optimization for transformers in parallel, called Parallel Losses Optimization (PLO), and is applicable to existing or future facilities and is adaptable to any type of transformer system. The method has been validated in 12 real facilities of different power and efficiency levels. Reductions in the losses of the studied transformers were up to 41% with respect to the initial losses. This demonstrates the beneficial operation of the PLO method proposed in this paper in a wide range of existing transformers or for future installations. The research has obtained patent pending status P201101267 in Spain.

1. Introduction

Transformation systems installed in buildings and industries connected to distribution networks ideally should ensure continuity of the energy supply at the point of consumption in the most efficient manner possible. Different international regulations require the assurance of supply through the installation of two or more parallel power transformers, such that maintenance operations can be performed on one of transformer without cutting off the supply; additionally, such an arrangement guarantees continuity of operation in case of failure. The total losses in a transformer are the sum of the no load and load losses. Over time, the energy efficiency of distribution transformers has increased, and the total losses have been reduced, representing an important advancement in electrical systems.

Transformation systems are an important percentage of the losses in electrical distribution systems, both in Europe and United States [1]. Despite the fact that transformer manufacturers [2] have systematically reduced losses by introducing new materials and manufacturing techniques [3,4,2,5,6], a significant amount of already installed equipment possesses energy efficiency values that are significantly lower in comparison to the systems manufactured today. Modern transformer manufacturing techniques allow development of systems with lower losses in comparison to the traditional systems, further involving reductions in the associated greenhouse gas emissions [2,5]. Transformer systems with low-losses reduce the instantaneous power demanded by the installation and, therefore, reduce the power associated with generation. In the case of electricity generation based on fossil fuels, this implies a reduction of CO_2 equivalent on the order of tons. With respect to systems installed in distributed generation grids [7,8], using renewable generation implies a reduction in the installed power and facilitates a better forecast of demand and enhanced system control.

The necessary investment in power distribution systems and the cost of electricity generation continue to increase; hence, technologies to reduce energy consumption are significantly in demand at present. Both electric power suppliers and final consumers in private facilities are directly benefited by the implementation of systems that reduce losses in the distribution transformers. Transformers are operated in every power distribution system, so that the energy savings associated with new technologies or transformation systems that increase the efficiency reach high values. Additionally, the newly installed transformers have no associated load losses, preventing secondary energy consumption without demand. In the design phase for a new installation, the choice between the use of a system of high efficiency versus one with major losses is directly related to the expected cost savings during use of the equipment. Analysis of the Total Owning Cost (TOC) is used as a tool for decision making by taking into account the sum of the cost of the transformer to own and the costs arising from losses during its lifetime [9]. Examples of the implementation

* Corresponding author. Tel.: +34 913 986 476/987 788; fax: +34 913 986 028.
E-mail address: acolmenar@ieec.uned.es (A. Colmenar-Santos).
[1] Tel.: +34 913 986 476; fax: +34 913 986 028.

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DEPT	distribution electronic power transformer	1	parallel transformer 1
GHG	greenhouse gas	2	parallel transformer 2
L	load (kVA)	dem	demanded
PLC	power line communication	L	losses (kVA)
PLO	parallel losses optimization (kVA)	N	nominal
PL	percentage losses	opt	optimal
S	transformer rated power (kVA)	par	parallel
TOC	total owner cost ($/kW yr)	SC	short circuit
U	transformer percentage impedance (%)	T	total
Subscripts			
0	no load		

of this method for the evaluation of facilities [10,11] have been reported, depending on the type of use [12–14] and specific to industrial and commercial facilities [15,16]. The TOC calculation evaluates losses in the transformer for load and no load modes to determine which type of transformer is the most appropriate based on the cost of losses during the life cycle of the equipment. This tool is used to make decisions in the design phase [17,18], specifically for manufacturing and purchasing equipment [19]. In this paper, the TOC is analyzed, and a new method is proposed, called PLO, which is aimed at the minimization of losses in the system during the device's entire life cycle.

For existing facilities with transformers in operation, it is necessary to consider techniques that allow reductions in the energy losses associated with transformers without requiring replacement of the existing transformers. The replacement of a device that is not damaged is justifiable if, after using a TOC analysis, the result profitability advice indicates discarding the existing system and the installation of a new transformer. This substitution is not economically viable in almost any case, so it is necessary to establish energy saving alternatives. For new facilities, the choice to use higher efficiency transformers can be profitable when the reduction in energy losses justifies the cost increase in comparison to that of a conventional transformer. Further, the existing transformers must be integrated in the new distributed generation systems, and the proposed approach for loss reduction methods facilitates this task, reducing the instantaneous power demand in the grid. In industrial facilities and commercial centers, transformers usually remain connected regardless of the power demand. However, many facilities exist with hourly, daily and monthly seasonality of use, so the transformation capacity installed is not always optimally adjusted. Additionally, based on forecasted expansions in the installation over time, it is typical to oversize transformer systems by a minimum value of 20%. Generally, the selection of one type of transformer with a large rating gives the maximum efficiency, which is further associated with simpler installation in comparison to use of more than type of one transformer. In large plants, two or more transformers of equal rating may be selected. This mode of operation is frequently required, but to ensure adequate performance, both transformer types must possess the same voltage ratio, the same percentage impedance, the same polarity and the same winding connections. For critical continuous operation plants or facilities, e.g., hospitals, power may be provided by two independent feeders. The feeders can be at similar or different voltage levels. In all such cases, each transformer may be capable of running the plant, such that in its normal operation each transformer only experiences 50% load. For non-continuous demand facilities, the load may be lower than 25% at times. For the non-continuous operation of plants with holidays or seasonal industries, switching one transformer to an off mode to save a portion of the load losses is generally considered, although the procedure has not been automated. The method proposed in this paper allows the transformers power to be adapted to the demanded power, incurring possible minor losses by connecting the transformer that ensures the required power and reducing the overall energy losses. Additionally, the proposed PLO method allows reduced losses in all types of facilities using parallel transformers, which is applicable to both existing and new systems, thereby allowing energy savings regardless of the efficiency of the transformer class.

This paper investigates and proposes a method of optimization for transformer utilities that is based on use of two transformers in parallel, as a standard solution for both industrial and commercial entities. This parallel approach is analyzed based on the losses and the reduction in losses associated with implementation of this method. A wide range of transformer combinations, with powers ranging from 100 kVA to 1600 kVA, were analyzed, providing transform powers from 200 kVA to 3200 kVA. Three transformer classifications, offering high, medium and low losses, were analyzed for each rated power. The transformers were characterized according to the parameters of load losses and no load losses, and the parallel behavior of the transformer sets was studied for all points of operation. The points of operation were calculated, and the total losses in the transformation utility for one or the other or both connected transformers were characterized. The Parallel Losses Optimization (PLO) was defined as the point of rupture; that is, the point at which it is more profitable to have connected only one transformer or both in parallel was established for each transformation power investigated. Additionally, the demand curves of four installations with installed power ratings of 650 kVA, 1260 kVA, 1630 kVA and 2600 kVA were studied to experimentally determine the potential savings. Several companies in the sector of transformer maintenance in Spain were consulted to shed light on the maintenance protocols for the systems and to calculate the potential savings associated with operation of the transformation system according to the PLO proposed in this paper. Transformer systems are widely used worldwide and will continue being installed during the coming years; hence, the energy saving potential is significantly high. The use of distributed generation systems will also increase the number of installed transformers.

The paper is organized as follows. Section 2 discusses the losses associated with transformers, both in parallel and unitary operation. Section 3 describes the methodology of the study carried out; in Section 4, the results are evaluated. The conclusions are presented in Section 5. Due to the general interest associated with this invention and the opportunities for cost reduction in electrical systems, the approach presented here is currently under patent pending status.

2. Energy losses in transformers

2.1. Transformer losses

Transformers are electric machines with high performance (more than 95%). The transformer is based on the use of two or