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Application of swarm algorithm to solving voltage unbalance problem in dc tram traction supply system

Abstract. *Problem of transforming ac voltage into dc voltage with the use of 6-phase Yyd transformer is discussed. Unbalance of secondary voltages enhances higher harmonics present in rectified voltage. Issue of equalizing secondary voltages with on-load tap changer is discussed, and tap changer settings are selected using ant colony optimization algorithm.*

Keywords: tram traction, voltage unbalance, multi-phase transformers, ant colony optimization.

Introduction

Supply of tram traction in Poland utilizes dc voltage, 600 V, which is obtained by transformation and rectification of ac voltage (usually 15 kV). Energy transformation circuit consists of multi-phase transformers and diode rectifiers; dc voltage contains ac component (apart from obvious constant component), its frequency is equal to multiplicity of supply network frequency. Depending on transformer-rectifier circuit used this may be 6*f* (3-phase transformer, 6-pulse circuit), 12*f* (6-phase transformer, 12-pulse circuit), rarely 18*f*, sometimes 24*f*. At present 12-pulse system is most popular in Poland, rectifiers may be connected in series or in parallel.

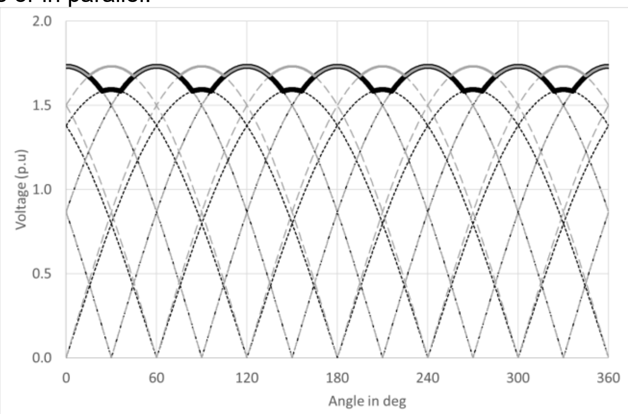

Fig.1. Dc voltage waveform: for balanced (thick grey line) and unbalanced (thick black line) voltages of secondary windings.

Secondary windings should be wound so that delta winding phase voltage (equal to phase-to-phase voltage) should be identical with star-connected winding phase-to-phase voltage. Since numbers of turns must be integer numbers, then this condition will never be completely fulfilled. Voltage unbalance between secondary windings' voltages results in increased pulsation in dc voltage (Fig.1).

Defining the problem

Effects of supplying the circuit with deformed voltage (containing 5^{th} and 7^{th} voltage harmonic) have also been considered. When secondary voltages are unbalanced, deformation of supply voltage results in even more increased pulsation of dc (rectified) voltage and emergence of successive new harmonic components. Existence of higher harmonics in dc voltage leads to emergence of higher harmonics in supply current, which in turn has a direct unfavourable bearing on the supply network. Minimization of dc voltage pulsation should lower higher harmonic content in the supply current.

Circuit modification and calculations

To balance secondary voltages, we propose to use a tap changer. In order to solve the issue of tap changer's settings under varying supply conditions, Ant Colony Optimization algorithm is applied. The task is to find minimum of function, where we have no information on function properties; the only information we have are function values in selected domain points. The algorithm works as follows:

1. On the basis of best-located ant (x^{best}) we create a new ant population; ants are randomly spread in the neighbourhood of best-located ant, one with most intensive pheromone trace: $x^i = x^{\text{best}} + \mathrm{d}x,\ \ i = 1,2,...N$, where interval $-\alpha \le \mathrm{d}x_j \le \alpha,\ \ j = 1,2,...m$ is chosen at random.
2. We select the best-located ant in new population ("updating" x^{best}).
3. Procedure described in 1-2 is repeated I^2 times.
4. Neighbourhood parameter is then narrowed down to $\alpha = 0.1 \cdot \alpha$
5. Procedure described in 1-4 is repeated I times.

   x^{best} thus obtained is treated as one of possible solutions of the task.

In our problem the objective function is defined as pulsation in dc (rectified voltage) and is dependent on gain coefficients (corresponding to tap changer settings). We have to select them in such a way, that result is minimum. When coefficients for different supply variants have been calculated, we have also found the harmonic spectrum of the rectified voltage for the corrected circuit.

Conclusion

We have demonstrated that in steady-state ac component of dc rectified voltage may be balanced by adjustment of voltage at one of secondary transformer windings with the help of on-load tap changer. We have investigated the case, when transformation circuit was supplied with distorted voltage, characterized by THD coefficient confined within limits set by appropriate legal regulations. Application of ant colony algorithm to the defined problem lets us determine the adjustment of tap changer at one secondary winding, and in this way the ac component between successive pulses becomes more balanced (in absolute values the difference may be as high as 27 per cent).

References

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