Optimal location of Power Quality Monitors in distribution grids based on MRA methodology

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Introduction

Distribution grids currently face news paradigms where Power Quality (PQ) has become one of the most important aspects for distribution system operators (DSO) and consumers. To ensure a PQ within the limits defined by international standards, there is a permanent need to monitor all parameters associated with the distributed voltage by the grid. This task is carried out using the installation of Power Quality Monitors (PQM) at strategic points of the grid. The main aim of this paper is to define a methodology to optimize the best location for the PQM installation. To achieve this target the Monitor Reach Area (MRA) matrix is calculated and an Integer Linear Programming (ILP) optimization model was used to find the best solution. Two case studies were carried out, in which residual voltage values were observed when three-phase short circuits are applied to all nodes.

Optimization model

The objective to be fulfilled will be to minimize the number of PQM placed on the power grid guaranteeing full observability of the grid. For this purpose, a linear programming model with binary decision variables has been constructed.
Let $N=\{1,\dots,n\}$ be the set of buses in the grid.
Consider the decision variables x_i where $x_i=1$ if a PQM is placed on bus i N and 0 otherwise.
The optimization model is given by:

$$\textit{minimize } f(x) = \sum_{i\in N} x_i \qquad (4)$$

$$s.t. \quad CM \times x \geq 1 \qquad (5)$$

$$x_i \in \{0,1\}, i \in N \qquad (6)$$

Where $x = (x_1, \dots, x_n)$ is the vector of decision variables and $1 = (1, \dots, 1)$ is a vector of n components, (4) is the objective function where is intended to minimize the number of installed PQM. Constraint (5) guarantees that whenever a fault occurs on one of the buses, at least one PQM will be able to detect it and constraints (6) impose the sign constraints on the variables ensuring that they are binary variables.

Methodology

A. Fault Position Methodology

The fault position method is used to calculate the voltage drops in transmission systems. It consists of individually short-circuiting each of the grid buses and then calculating the value of the residual voltages at the other buses to obtain the values of the voltage drops across the grid. A matrix with a dimension equal to the number of buses in the grid is then built with all the values obtained for each fault position. This method makes it possible to get the most vulnerable areas by the short circuits applied at each bus. The residual bus voltages are given by:

$$V_{ij} = 1 - \frac{Z_{ij}}{Z_{jj}} \qquad (1)$$

where V_{ij} represents the residual voltage present at bus i when j is short-circuited, Z_{ij} is the short-circuit impedance of bus i upon a fault at j, and Z_{jj} is the short-circuit impedance of bus j when j is short-circuited.
This method makes it possible to build the Fault Voltage Matrix (FVM) (2), which stores all the information about the residual voltage values obtained in the grid. Assuming that the grid has n buses $i, j \in \{1, \dots, N\}$

$$FVM = \begin{bmatrix} V_{11} & V_{12} & V_{13} & \cdots & V_{1n} \\ & \vdots & & \ddots & \vdots \\ V_{n1} & V_{n2} & V_{n3} & \cdots & V_{nn} \end{bmatrix} \qquad (2)$$

B. Monitor reach area

In order to study the behavior of a power grid when it experiences severe voltage dips, the MRA method was developed. The MRA concept is defined as an area of the grid where whenever a fault occurs, it can be detected by at least one PQM. Several types of short circuits that can affect the grid in a harmful way. In this paper, it will be studied how three-phase (L-L-L) short circuits affect a distribution grid. After obtaining the FVM, the MRA concept is applied, which generates a binary matrix. The entries of the new MRA matrix assume values "0" or "1" depending on the residual voltage values obtained in FVM. Placing "1" at position $(i; j)$ indicates that point j will have to be covered by a PQM placed on the bus i, which corresponds to a situation where the residual voltage is less than or equal to a preset value. On the other hand, the value "0" indicates that point j does not need to be covered by a PQM placed on bus the i, which corresponds to a situation where the value is higher than the preset limit, according (3).

$$MRA(i,j) = \begin{cases} 1, & V_{ij} \leq p \\ 0, & V_{ij} > p \end{cases} \qquad (3)$$

Results

A. IEEE 13 Bus System

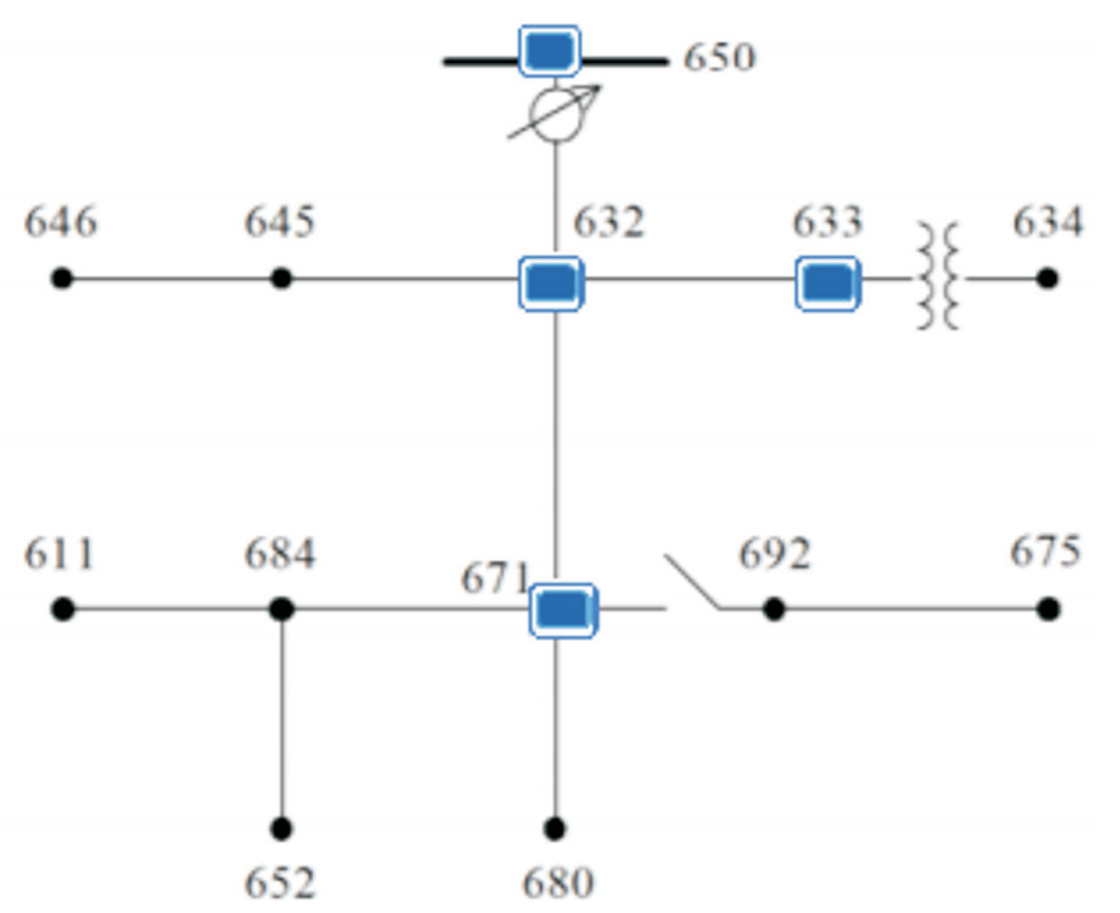

Fig.1 Optimal PQM locations for 13 bus system with 0.4 p.u. threshold.

B. IEEE 33 Bus System

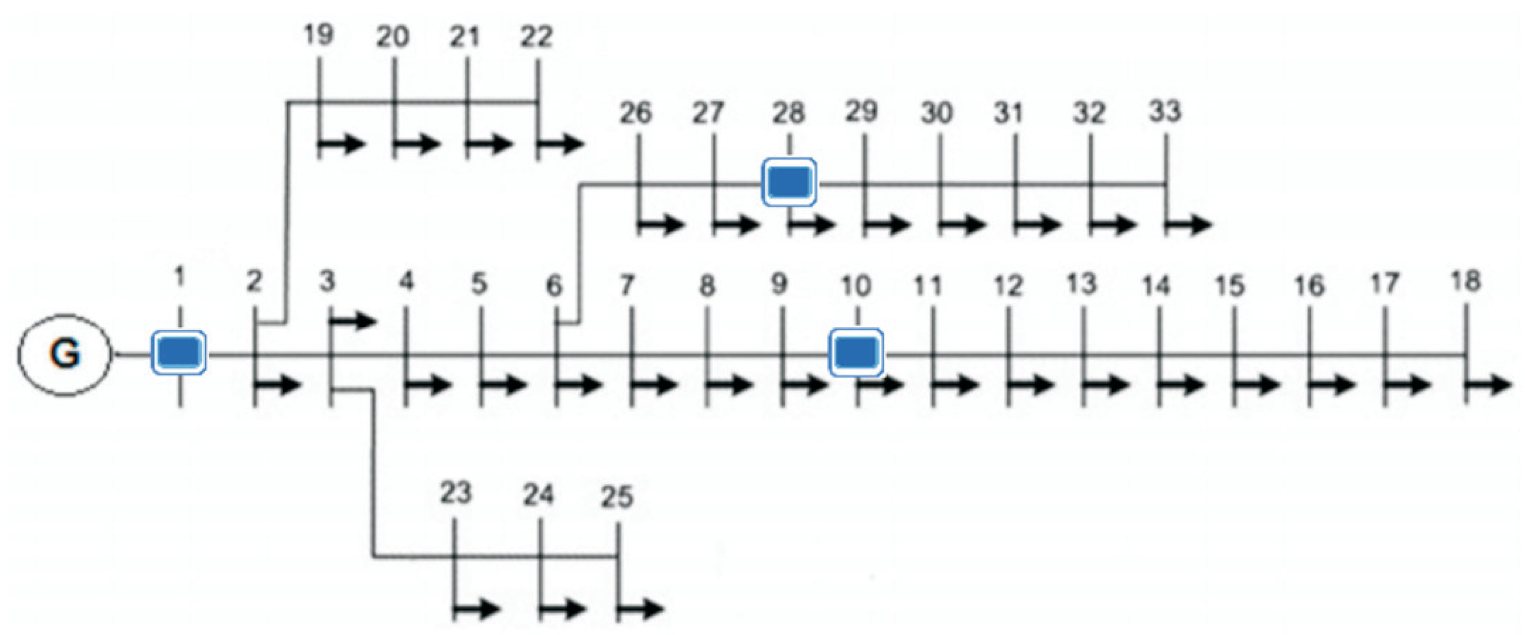

Fig.2 Optimal PQM locations for 33 bus system with 0.4 p.u. threshold.

Conclusions

The used methodology, with the TMRA matrix and the integer linear programming optimization model, proved to be very effective, allowing good observability of both studied grids with a minimum number of PQM, as proposed in the objectives. Furthermore, the optimization model developed allows obtaining the optimal solution with reduced processing time, less than one second, which suggests that it is easily applicable to larger grids.