Comparison of approach strategies with dynamic load models in electrical power systems

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Abstract. This work contains the comparison of some strategies for the approximation of the load of an electrical system with the model of general dynamic load, and in this way obtain a sensitivity of the load connected to the system, this in order to be able to tend to future load aggregations to a given network. The document initially exposes dynamic and static loading models, focusing interest on the general model, dynamic model base for the analysis, then comments on the methods of load estimation and emphasis is placed on the meta-technical technique at colony system, after explanations of the perturbations and the procedures to be followed in the analysis proposed with the DigSILENT software, finally the comparative results between the estimation and measurement technique are exposed.

1. Introduction
The accelerated increase of the population in the last fifty years, has been reason that the demand of electrical energy has also increased; leading the electrical power system (EPS) to limit conditions in its operation. On the other hand, the environmental crisis that the current world is experiencing has encouraged the development of non-conventional generation systems, as well as the concept of smart grids, which present a new paradigm for the traditional EPS. From the previous considerations, all the upcoming changes require a stable, reliable and robust system in which the operating conditions are dynamic. For these reasons, dynamic load modeling has become an area of constant and ongoing research with great challenges due to the varied and complex nature of the loads. Because the definition of load covers all the traditional elements that consume power, such as motors, lamps, capacitors, regulators, lines, transformers, among others, we have the difficulty of not being able to represent each of these elements individually, but of added way. In this virtue, it is necessary to carry out a study by means of which a good representation of the loads is guaranteed; that is, with a reasonable margin between the relevant information of the individual loads, and their aggregate behavior in the power system. Consequently, dynamic load modeling must be compared with the current state of the system, this is achieved by a strategy known as measurement-based approximation. Which takes measurements throughout the network, and through optimization strategies allows the estimates to follow the real reference of the system [1].

For the analysis of electrical systems, we must inexorably resort to the modeling of the elements that comprise it, among which we can mention lines, transformers, generators and finally loads. The latter, in recent years, has had great relevance, due to its direct interference in stability studies and the growing interest in its response to contingencies in the power system that supports it. Because of this growing interest, it is possible to find in the literature a great variety of models that try to describe the behavior of the loads in their static and dynamic parts. This is achieved by two widely studied strategies. The
first, known as the component-based approach, consists of recompiling individual information from each of the charges present in a system and then condensing it into a single charge. The second, known as the measurement-based approach, consists of collecting measurements in the substation, such as voltages and active and reactive powers during a disturbance in the system. These measurements will be used to estimate the parameters of the load model, which minimize the difference between the real power system and the response of the model in question. In such a virtue, it is intended to perform a study by simulation to solve the above problems, as well as perform an analysis and validation of the general model against the conditions mentioned under different disturbances and obtain an effective comparison of the methods used [2].

1.1. Modeling from measurements

In the specialized literature you can find two strategies for the estimation of dynamic load model parameters. The first strategy is the measurement-based approach, which is based on taking direct measurements at representative points in the network to determine the sensitivity of frequency, voltage and active and reactive power of the load. This procedure has the advantage of using real-time measurements of the system under study, allowing a normal operation monitoring of the system against stationary variations. The second strategy is the component-based approach. This methodology consists of collecting measurements in the substation, such as voltages and active and reactive powers during a disturbance in the system. These measurements will be used to estimate the parameters of the load model, which minimize the difference between the real power system and the response of the model in question [3].

1.2. Load models

It should be mentioned that load models are dependent on the response in voltage and frequency, and are also subject to the particular demands and challenges presented by each case study, such as stability analysis, small signal, over voltage, deficit between generation and demand between others. In conclusion, a load model is the mathematical representation between the magnitude of the voltage and the active or reactive power of the bus or measuring point, which is essential for the prevention and safety of the planning and operation of the system.

These have a low implementation complexity, due to their mathematical structure, they also have great flexibility and capacity in the representation of different loads. Among the most used are the exponential model and the polynomial [4].

1.3. General model

The General load model is represented by block diagrams, which satisfy Equations (1) and Equation (2). The general model depends on its internal parameters and the variations in voltage and frequency, which allow to define the behavior of a dynamic load before the disturbances that affect the system as shown in Equations (3) and Equation (4).

\[
P_t = P_e \left(1 + \frac{K_{pf} + sT_{pf}}{1 + sT_1} \Delta f + \frac{K_{pu} + sT_{pu}}{1 + sT_1} \Delta u \right) \tag{1}
\]

\[
Q_t = Q_e \left(1 + \frac{K_{qf} + sT_{qf}}{1 + sT_1} \Delta f + \frac{K_{qu} + sT_{qu}}{1 + sT_1} \Delta u \right) \tag{2}
\]

\[
K_{pu} = aP_e a^P + bP_e b^P + cP_e c^P \tag{3}
\]

\[
K_{qu} = aQ_e a^Q + bQ_e b^Q + cQ_e c^Q \tag{4}
\]
As can be seen in Equations (1) and Equation (2) the constant $T_t$ is the time constant of the dynamic load, the constants $T_{pt}, T_{qt}$ are defined as active and reactive power coefficients that depend on the frequency, $T_{pt}, T_{qt}$ correspond to the time constants for the active and reactive power that depend on the frequency, $T_{pu}, T_{qu}$ are the time constants of the voltage dependence for the active and reactive power. $T_{pu}, T_{qu}$ are internal variables of the model, which are calculated as a function of the coefficients and exponents of the static load as shown in Equation (3) and Equation (4).

1.4. Estimation methods

There are complex combinatorial optimization problems in various fields such as economics, commerce, engineering, industry or medicine. However, often these problems are very difficult to solve in practice. The study of this inherent difficulty in solving these problems has led the scientific community to formulate a number of models, which are still trying, every day more, to approach more optimal solutions in a more efficient way, achieving satisfactory results in times of increasingly smaller execution. Because of large problems and combinatorial characteristics, exact models, and even heuristics, are ineffective; metaheuristic techniques appear as very reasonable alternatives to address them, where different experiments have already demonstrated the benefits of these models [5].

1.5. Optimization by ant colony system

Optimization algorithms for the optimization by ant colony system (ACS) are approaches inspired by the natural behavior of ant colonies. ACS has been successfully used in the solution of combinatorial problems, being its basic elements: the artificial ants and the matrix of pheromones $\tau$. The pheromone matrix $\tau$ is the indirect means that ants use to communicate, depositing and simultaneously censoring pheromones during a journey in the construction of a solution on a graph $G(E,V)$. Basically, the choice of a node $j$ while an ant is in a node $i$ is given by the following probabilistic Equation (5):

$$p_{ij} = \frac{\tau_{ij}^\alpha \eta_{ij}^\beta}{\sum_{k \in N_i } \tau_{ik}^\alpha \eta_{ik}^\beta}, \text{ yes the link } (i,j) \in E; \ p_{ij} = 0, \text{ in another case},$$

where: $\tau_{ij}$ represents the level of pheromones deposited in the link $(i,j)$, $N_i$ is the set of feasible nodes, neighbors of the node $i$, $\eta_{ij}$ represents the visibility of the link $(i,j)$, $\alpha$ and $\beta$ and are parameters that determine the relative importance between $\tau_{ij}$ and $\eta_{ij}$.

Equation (5) includes the concept of visibility of the ants which in its simplest form is the desirability according to some parameter associated with the links [6].

1.6. Quadratic relative error

The quadratic error applied to the problem of parameter estimation consists of defining the parameters that best fit the load model, considering the measurements obtained from the system during its normal operation.

With the relative error we try to obtain the smallest difference between the simulated signal and obtained by means of measurements, by adding the square of the error at each instant $k$, in order to obtain as can be observed in Equation (6).

$$\min \frac{1}{N} \sum_k \left[ (P_{km} - P_{ks}(\theta))^2 + (Q_{km} - Q_{ks}(\theta))^2 \right],$$

where $N$ is the number of samples, $P_{ks}$ and $Q_{ks}$ are the active and reactive powers simulated by the load model at a time $k$; $P_{km}$ and $Q_{km}$ are the active and reactive powers obtained by measuring the load at the same instant $k$.
1.7. System disturbances

In the implementation of the disturbances to capture the database, three types of events are generated, which have different characteristics between voltage and frequency disturbances, so that voltage variations do not exceed $\pm 5\%$ of the nominal voltage and that the variations in frequency are quite slight between $\pm 5\%$ of the nominal frequency.

- Event 1: A three-phase fault is generated in the 230 KV ring in the line that connects the 12 branch with the 3 branch, in which they cause a voltage disturbance of $\pm 5\%$.
- Event 2: Disconnection of line BC is generated.
- Event 3: A large load is entered in the bar C1 and it is disconnected after a certain time.

2. Results

To obtain a load model based on measurements, the correct selection of the structure of the model is required, which must be consistent with the voltage and power measurements that are available so that complete information about the behavior is available [9]. Static as dynamic load and to estimate the parameters of the model. There must be software that facilitates the manipulation and analysis of the load model. Finally, you must select a flexible and accounting optimization method that throws the solution parameters of the problem.

With these conditions, the parameters representing the selected model will be estimated using the ACS heuristic meta technique described in Figure 1 which seeks to reduce the quadratic error between the active and reactive power measured in the points of interest with respect to the simulation of the model. The methodology proposed in 1 is used [10,11].

After having characterized the parameters that best fit in the representation of the load in the specified case, the verification of the results obtained through the simulation of the model is performed. Figure 2 shows test network portion selected in this work.

![Figure 1. Parameter estimation methodology with ACS.](image1)

![Figure 2. Portion to study of the test network.](image2)
### 2.1. Test nomenclature

Figure 3 shows the results and Table 1 the errors. The following criteria are defined: the dotted line in red represents the actual signal taken at the desired bar.

- The blue signal refers to the estimated signal with the implementation of the general model in the measurement bar, replacing the load connected to it.
- The numerals a, c, e represent the active power in MW for events 1, 2 and 3 respectively.
- The numerals b, d, f represent the reactive power in MVAr for events 1, 2 and 3 respectively.
- The x axis of the graphs corresponds to the simulation time in seconds.

![Figure 3. Estimation and comparison using the ACS method.](image)

| Event  | Quadratic Error |
|--------|-----------------|
| Event 1| $4.6625 \times 10^{-4}$ |
| Event 2| $8.2222 \times 10^{-6}$ |
| Event 3| $3.6503 \times 10^{-4}$ |

### 3. Conclusion

The response of the general load model was evaluated satisfactorily from the load aggregation approach, which considers a network that feeds a wide variety of loads, distancing itself from this procedure which some authors suggest represent loads that are connected in a single in addition, a high capacity of the model was found to represent perturbation situations in the high magnitude network. The relevance of the optimization methods is also evident when estimating the best parameters of the model, a technique carried out under the previous analysis of the model. feasibility of the parameters and their dimensioning to be compatible with the software that implemented the model.

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