Exponential Based Load Model for Baghdad Distribution Feeder

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Abstract:

Distribution feeders in Baghdad comprise different load classes, those classes differ in load component, characteristics and sensitivity to network variables. In view of this fact, applying any dynamic study to those feeders requires proper modeling of loads, otherwise, unfavorable results obtained. Realistic load component varies in relation to both system voltage and frequency, and this variation is related to load type and sensitivity, that may alter studies by deliveringnon -desired results. Proper modeling leads to desirable decisions,correct and realistic results, and undoubtedly will reduce efforts and expense of the un-justified network modifications. In this work, residential load mix feederisstudied,the load characteristic is acquired, and thennetwork componentsand loads are presented using voltage-frequency dependable exponential load model. The results obtained arerecommended to be implemented in distribution network studies and dedicated software within Baghdad network.

Keywords: Load Modeling, Load Representation, Dynamic Studies, Distribution Network

تمثيل الاحمال بنموذج ذو صيغة أسية لشبكة مغذي

توزيع في كهرباء بغداد

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المستخلص:
تتضمن مغذيات شبكة توزيع كهرباء بغداد أنواعاً متنوعة من الاحمال تختلف عن بعضها بالسلوك والخصائص والحساسية لمتغيرات النظام . ان تنفيذ ايۃ دراسات واقعية على هذه المغذيات يتطلب التمثيل الامثل للاحمال وبخلافه تنتج هذه الدراسات نتائج غير مثالية.
تتغير الاحمال الواقعية عند تذبذب الفولتية وتردد النظام ويعتمد هذا التغير على نوع الحمل وحساسيته ومن الممكن ان يؤثر في الدراسات الديناميكية لانظمة التوزيع . ان التمثيل الامثل للاحمال يقود لقرارات مثلى ونتائج واقعية صحيحة وبالتاكيد يقلل من كلفة التطوير والتنمية غير المبررة للشبكات في حال تمثلها بشكل ثابت.
تضمن هذا البحث دراسة نموذج لمغذي ذ ي حمل سكني ،حيث تم تسجيل خصائص الحمل ومن ثم تمثيله باستخدام نموذج أسي مع الاخذ بنظر الاعتبار تاثير تغير الفولتية والتردد على تلك الاحمال ، وخرجت هذه الدراسة بنتائج واقعية يوصى باستخدامها في دراسات شبكة توزيع كهرباء بغداد وبرامجياتها.

Introduction

The term load in power system representation refers to a large number of individual power consuming devices connected to specific buses. Those loads may consist of multiple classes like residential, commercial, industrial and rural. Each load class may also contain several dissimilarcomponents like pumps, lights, heaters, etc.

Realistic distribution network operation undergoes voltage and frequency variation constantly, due to the fact that load components are mutually related to that variation; load performance willoscillateand alter the network operating conditions regarding its sensitivity to voltage and frequency change, and may lead to adverse impacts [1].

In dynamic studies, like transient stability and load flow, it is essential to represent each load with its corresponding equivalentmathematical model. The efforts of IEEE taskforces [2] , CIGRE [3] and EPRI [4] projects result in various load models in addition to interesting characteristic data for large number of load components. The results obtained through cooperation between

General Electric [5] and other electricity utilities to facilitate the implemented operational and control programs to realize correct solutions in case of fault, load forecasting, network modification, future expansion, contingency analysis, in addition to voltage and rotor angle transient stability studies.

Load Model

To obtain accurate loadmodel, two approaches are applied by electricity utilities worldwide; measurement-based and component-based. In this work, component-based approach is used involving load characteristic data acquisition analysis with the contribution of previous load study results achieved by IEEE taskforces, CIGRE and EPRI projects. In this approach, the entire study is based on actual distribution network data result in more accurate model.

When voltage and frequency vary evenly within acceptable boundaries, it is not suitable to continue representing the loads as fixed rated power consumers, in that variation influences the active and reactive power of load. In special load component, like lighting, thepower may decay to zero during large variation, thus a mathematical expression is necessary to represent the load sensitivity to both voltage and frequency , the following model is employed in this work:

$$\frac{P}{P_o} = P_{fv}[1 + kpf(f - f_0)](V/V_o)^{kpv} + (1 - P_{fv})(V/V_o)^{kpv} \qquad (1)$$

$$\frac{Q}{P_o} = Q_{fv}[1 + kqf(f - f_o)](V/V_o)^{kqv} + \left(Q_o/P_0 - Q_{fv}\right)(V/V_o)^{kqv}[1 + kqf(f - f_o)] \qquad (2)$$

WhereV_o,f_o, $P_o$and$Q_o$and are the rated load voltage, frequency,active and reactive powerconsecutively.

V, f ,$P$and$Q$are the current loadvoltage, frequency , active and reactive power consecutively.

kpf and $kpv$are the active power frequency and voltage sensitivityparametersrespectively.

kqf andkqv are the reactive power frequency and voltage sensitivityparameters respectively.

P_{fv} and Q_{fv} are the percentvoltage-frequency sensitive part of active and reactive powerrespectively.

Thisform of load model is a mathematical exponential expression that represents the load's active and reactive power at any instant of time as a function of voltage and frequency variation for voltage and frequency dependable loads, withregard to load component sensitivity.

The first part of the above form represents the voltage-frequency sensitive loads, while the second includes voltage sensitiveportionof loads only. This model is termed static-load model, it is applicable to present residential static loads and may also be used as an approximation for dynamic models.

Load Representation Approach

In this work, component-based technique is used inrepresentingthe proposed mode under investigation.In this technique,realistic load characteristic data is essential and should be provided for many hours. The required load characteristic parameters are the voltage, frequency, and power-factor in addition to power variation.

The following approach is achieved to represent the loads in such a way as to obtain realistic and accurate results:

1. **Each feeder is equipped with data acquisition devices that are capable of recording load characteristic data at specific intervals.**
2. **Initial voltage and frequency sensitivityparameters areobtained from typical load characteristic data reported by EPRI studies [6].**
3. **The rated active and reactive power is deduced by fitting the above data in procedure 1 and 2 into the load model equations.**
4. **Once rated power is achieved, the load characteristic data is used to obtain the actual voltage sensitivity factor using the following expressions:**

$$kpv = \ln\left\{\frac{U_p}{P_{fv}\omega_{fp} - P_{fv} + 1} - U_v\right\} \quad (3)$$

Where

$$U_p = \frac{P}{P_o} \quad , \quad U_v = \frac{V}{V_o} \quad , \quad \omega_{fp} = 1 + kpf(f - f_o)$$

Subjected to the constraint :

$$minimize \quad \epsilon_{r(pv)} = kpv'' - kpv'$$

Where $\epsilon_{r(pv)}$ is the error factor related to the active power voltage sensitivity.

In similar mannar, actual frequency sensitivity factor is obtained using the following expression:

$$kqv = \ln\left\{\frac{U_q}{\omega_{fq}} - U_v\right\} \qquad (4)$$

Where

$$U_q = \frac{Q}{Q_o} \quad , \quad \omega_{fq} = 1 + kqf(f - f_o)$$

Subjected to the constraint:

$$minimize \quad \epsilon_{r(qv)} = kqv'' - kqv'$$

Where $\epsilon_{r(qv)}$ is the error factor related to the reactive power voltage sensitivity.

The same procedure is implemented to achieve *kpf* and *kqf*.

5. **Steps 3 and 4 are repeated until the desired error factors areachieved.**

Several iterations may berequiredin order to reduce error factors, which reflect realistic and accurate load characteristic factors.

Load Aggregation Strategy

In this work, two strategies are used:

1) **Feeder-Bus Model**

   Single load model is achieved in this strategy by combining all network load-buses into one feeder-bus using aggregation theory [7]. Network aggregation technique is implemented to reduce the network into single distribution impedance $Z_D$and load model.

2) **Transformer-Bus Model**

   In this strategy, each transformer is assumed as a load-bus and the load model is presented toall buses. For each load-bus, the fractional load model equation is formulated by estimating the transformer fractional KVA rating ρ in addition to transformer load factor as follows:

$$\left.\frac{P}{P_o}\right|_{tr(i)} = \rho_{(i)} \times L.F_{(i)} \tag{5}$$

Where

$$\rho_{(i)} = {S_{r(i)}}\Big/{\sum_1^n S_{r(i)}}$$

Both strategies are explained as shown in figure 1.

Test System and Results

The proposed model and representation approach is tested on 11kVresidential feeder within Baghdad distribution network, known as114-MOHET as shown in figure 2. All network components are presented, including transformers and power factor correction capacitors.

The load characteristic acquisition is obtained on the feeder main. In this procedure, the feeder is equipped with a modern computer-based protection, communication and monitoring device capable of recording power, power-factor, frequency,voltages, currents and allrequired load characteristic parameters. All network components are combined into single impedance Z_D to implement feeder-bus strategy.

To implement the second strategy, each distribution transformer is assumed to introduce a load-bus, using transformer-based strategy,the load parameters per each transformer are deduced by presenting the transformer fractional rating and the load factor.

Inthe present approach, all load model parameters like voltage, frequency deviation, standard voltage and frequency sensitivity factors are imported tothe load model mathematical expressions. The active and reactive power are obtained after accomplishing9 iterations in case of implementing feeder-bus strategy, while it takes 16 iterations to reflect the best results when applying transformer-bus strategy, at the end of the iterations, minimum error is achieved and hence it reflects the best realistic sensitivity factors as shown in figure 3.

All the above steps aretranslated into MATLABcodes result in a developed package named *LoadExpo*capable of modeling any distribution feeder loads.

Conclusion

The load modeling is essential when accurate and realistic results of dynamic studies are required. In this work, using standard values of load characteristic parameters as initial values to the load presentation approach reflects good results after few iterations.

The modeling approachand results obtained arehighly recommended for use in Iraqidistribution network dynamic studies,analysis, control andmonitoring software to achieve optimistic decisions, and hence, to avoid studying and operational faults, un-justified modification cost and unrealistic load growthconcerning.

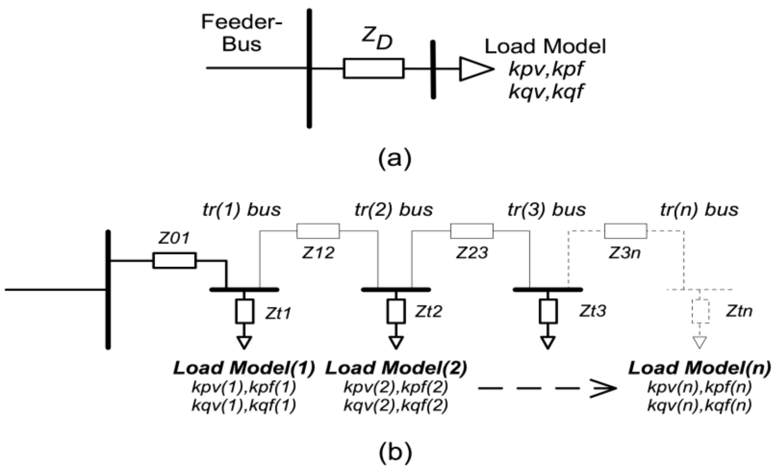

Figure 1
(a) Feeder-load model (b) Transformer-bus load model

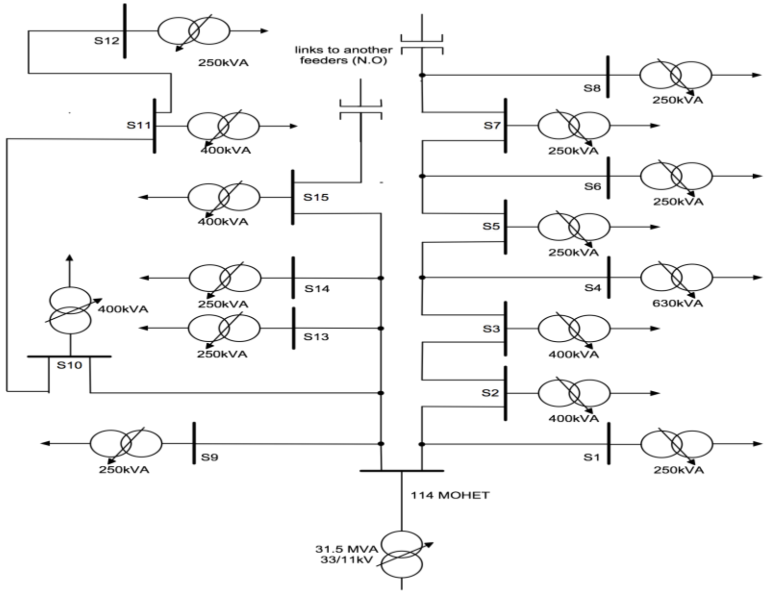

Figure 2
114-MOHET SLD

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       Load Modeling Using Exponential Form
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 => Feeder-Bus Load Model Strategy Parameters <=

              Kpv=1.12   kpf=0.87

              kqv=2.24   kqf=-1.87

          number of iterations = 7

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 => Transformer-Bus Load Model Strategy Parameters <=

kpv( 1)=1.15   kpf( 1)=0.72   kqv( 1)=2.63   kqf( 1)= -1.35
kpv( 2)=1.03   kpf( 2)=0.90   kqv( 2)=3.01   kqf( 2)= -1.56
kpv( 3)=0.98   kpf( 3)=0.75   kqv( 3)=2.18   kqf( 3)= -1.82
kpv( 4)=1.01   kpf( 4)=0.83   kqv( 4)=2.91   kqf( 4)= -2.34
kpv( 5)=1.30   kpf( 5)=0.90   kqv( 5)=3.07   kqf( 5)= -1.93
kpv( 6)=0.99   kpf( 6)=0.84   kqv( 6)=2.74   kqf( 6)= -2.00
kpv( 7)=1.26   kpf( 7)=0.79   kqv( 7)=2.29   kqf( 7)= -1.76
kpv( 8)=1.00   kpf( 8)=0.90   kqv( 8)=2.53   kqf( 8)= -2.25
kpv( 9)=1.40   kpf( 9)=0.89   kqv( 9)=3.00   kqf( 9)= -2.01
kpv(10)=1.16   kpf(10)=0.76   kqv(10)=2.34   kqf(10)= -1.39
kpv(11)=1.21   kpf(11)=0.80   kqv(11)=2.21   kqf(11)= -1.62
kpv(12)=1.43   kpf(12)=0.91   kqv(12)=2.95   kqf(12)= -1.92
kpv(13)=1.29   kpf(13)=0.83   kqv(13)=2.20   kqf(13)= -2.05
kpv(14)=1.50   kpf(14)=0.74   kqv(14)=2.41   kqf(14)= -1.48
kpv(15)=0.97   kpf(15)=0.90   kqv(15)=2.93   kqf(15)= -2.31

          number of iterations = 16
>
```

Figure 3
LoadExpo output for 114-MOHET

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