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Crete, Greece

Editors: George Contaxis, Manolis Antonidakis

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DYNAMIC MODELING OF ELECTRICAL LOAD DEMAND

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Abstract

In this paper the total installed load namely, the electrical load demand model for dynamic model of the electrical energy demand is provided.
Based on this definition, electrical energy demand equals the product of the electrical installed power and the total time required for commissioning, while considering the simultaneous coefficient.

$$d_{EE}(t) = U_D(t) . e_D(t)$$

Where:

$d_{EE}(t)$ Is Demand for Electrical Energy in One Year (Gwh), $e_D(t)$ is Electrical Devices Installed [G.W] and $U_D(t)$ is Utilization Duration of the Devices [hours per year].
Therefore, identifying the $e_D(t)$ function or the load demand function by linear or non-linear methods, based on the principal parameters, and determining the main part of deciding factors, is given in this article.
Linear models furnish identifying the effective exogenous factors in the model. Then the main model in the framework of non-linearity is given. Therefore, factors like energy prices, level of household income and production rate are shown to be effective in the model. In this study, statistical data of the past 33 years are made use of.

Keywords: Electrical Load Demand, Dynamic Modeling, and Load Demand Model

Introduction

Electrical energy consumption in Iran has an average 8% rate of rise. Programs of reducing energy consumption are under way based on the government's second and third five-year development plans. Defining the energy consumption model has an important role in this success. Identifying effective factors in all sectors (domestic, commercial, services, public, industry and agriculture) is possible by time series of all data. Defining a dynamic model, by visualizing a mental model and investigating the relationships between its components is visual. In this paper, emphasis is put on determining a model for load demand.

Structure of the model and the input variables [1]

In this model, energy consumers are domestic and working sectors. All industrial, commercial and agricultural uses are seen as one lot and those of domestic and public as a separate lot. The quantity of the installed loads in the first lot is related to production capacity in those sectors. In the second lot, population, increasing domestic electric appliances, social development and the living standard determine the total installed load. The structure of the suggested model is as follows:

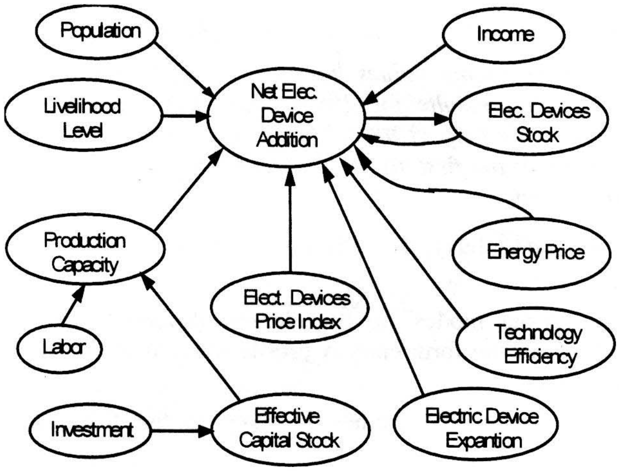

Fig 1:Structure of electrical load demand model

Identifying the load demand model (linear model)[2,3,4]

In the linear model, the entries are denoted by ui and the error sentence by C (q), and therefore:

$$x_D(t) = \sum_{i=1}^{2} \alpha_i \, x_D(t-i) + \sum_{i=1}^{4} \beta_i \, u_i(t) + C(q)\, \varepsilon(t) \quad (1)$$

$$e_D(t) = e_D(t-1) + x_D(t) \quad (2)$$

Where, $x_D(t)$ is a derivative of the load. In the linear model under study, the effective factors such as purchasing power, production capacity and the population plus a sentence are constant.
In this manner, the (u_i) entries of the linear model are as follows:

u_1 : $S_F\{\Delta(y/p)\}$, $S_F\{\Delta(y/p_{ED})\}$, $S_F\{\Delta(y_N/p)\}$, $S_F\{\Delta(y_N/p_{ED})\}$

u_2 : $Sm(S_F\{\Delta(y_P)\}, 10).e^{.05t}$, $Sm(S_F\{\Delta(y_P)\}, 15).e^{.05t}$, $Sm(S_F\{\Delta(y_P)\}, 20).e^{.05t}$ (3)

$u_3: \Delta p_O, \Delta(p_O \cdot e^{0.1t}), \Delta(p_O \cdot e^{0.05t})$

$u_4: 1, e^{0.02t}, e^{0.03t}, e^{0.04t}; \; t = 0, 1, \ldots, 32,$

$$\mathrm{Sm}(x,\alpha) = \frac{1}{1+e^{-\alpha x}}$$

Note that the S_F is used for harmonizing the variable profile.

The Sm (x, a) = 1/(1+e**[-ax]) is the Sigmoid function.

These entries [5,6] and their respective combinations, assuming a uniform model of the average first-degree driver for error sentence 144, provide the model.

Besides the displacement/CHANGE in the order, unifying and differentiating for the first entry, 144 other combinations are obtained, namely 288 models are calculated.

$$u_1: \Delta(S_F\{y/p\}), \Delta(S_F\{y/p_{ED}\}), \Delta(S_F\{y_N/p\}), \Delta(S_F\{y_N/p_{ED}\}) \quad (4)$$

Note that the output values have also been unified.The identification results for 288 models and classifying them with the help of neural fuzzy logic determination technique in the first six grades, leads to the following combination:

$$y/p \;\; \mathrm{Sm}(S_F\{\Delta(y_P)\}, 15).e^{.05t}, \Delta(p_O \cdot e^{0.1t}) \quad (5)$$

Among various modes, no considerable differences are observed for the forth entry.A profile trend as e^(.02 *t*) is desirable.

Specification of the models is given in the following table.

T, Statistics of purchase power in not meaning for the level of Ps 0.05. So the model should be improved.

The amount of dynamic utilitarian of selected model generally is acceptable. But regarding other parameters is not so good.

System response of step function approves the subjects and shows majority frequently.

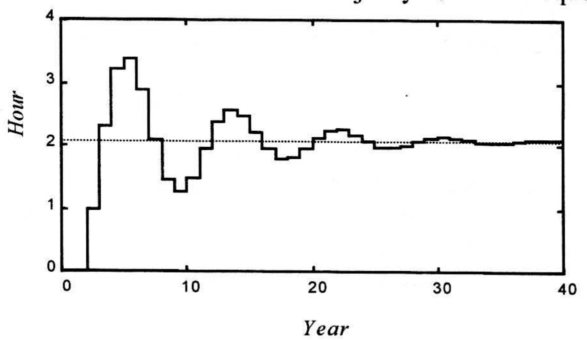

Fig. 2: Step response for no. 17 model (linear)

Figure [3] output of 8th model comparing with smooth output shows. Result of forecasting and simulation of other model (tables) show not much difference with the Curves. In the next step, effective factors are experimented in nonlinear structure.

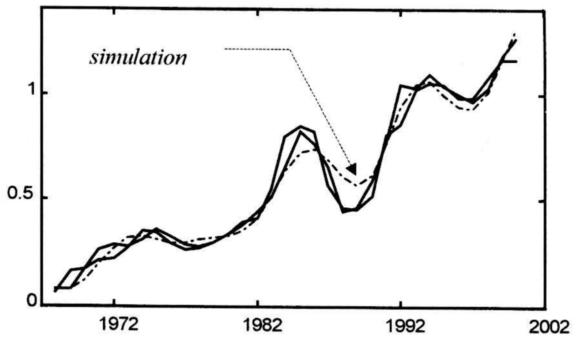

Fig. 3: Estimation output for no.8 model

Identification and estimation of nonlinear model

Non – Linear structure for electrical demand is surveyed based on functional shape with using of linear model and sigmoid and exponential function.

$$U(t) = \mathrm{Sm}(S_F\{\Delta(y/p)\}, \mu)\,[\beta_1 \mathrm{Sm}(S_F\{\Delta y_P\}, \theta)\, e^{\sigma t} + \beta_2 \Delta p_O e^{\gamma t}]^{\lambda} \quad (6)$$

Above model besides of the low parameters of related to dynamic of system includes more 7 parameters.

Identifying of this model and estimation of parameters and adding one parameter f ECM result in 10 parameters. 39 samples have problem for estimating all the parameters.

A parameters is assumed 15, result of identification for remained 9 parameter have in the following table. Although the error is decreased and R^2 increased, but level of meaning full of parameters is low. So the model is not acceptable.

Hence, there is no choice but to reduce the number of the parameters, in the next step, σ and γ are also fixed at 5% and 12% respectively. Identification results and parameter estimation for the 7-parameter model are given in the following table.

Although the results have improved according to the ready t-std standard, but one of the parameters is still unreliable. Therefore, the μ parameter is fixed at 0.6 in the next step.

The results appear most desirable. But apart from the mentioned specifications in the table, some other important details should be considered carefully. The model's dynamic behavior is particularly of importance and should be logical and correct.
The dynamic coefficients of this model are very close to those of the linear model, as are their behaviors. For comparison, for comparison, it is stated that the values of and α_1 and α_2 coefficients in the linear model are respectively equal to -1.31 and 79. The position of the two model poles is seen in the following diagram. As seen, the non-linear model poles have less stability. It is notable that the oscillations period *wn* has been approximately constant.

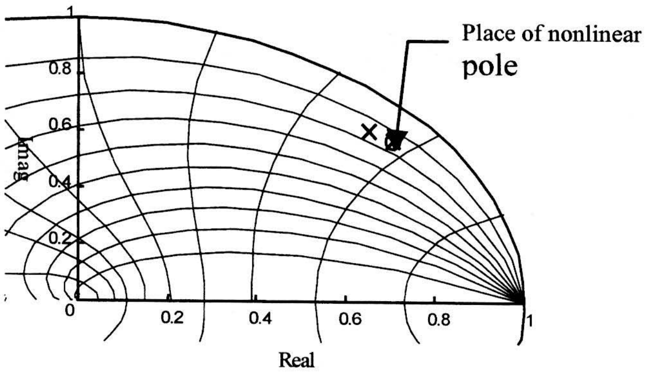

Fig 4: Places of poles

In the other step of non-Linear modeling smoothing of output added to the end of the model. There for the resulted model in a mathematical expression would be.

$$x_D(t) = S_F\{\alpha_1 x_D(t-1) + \alpha_2 x_D(t-2) + \dots$$

$$Sm(S_F\{\Delta({}^{y}/p)\},\ \mu)\ [\beta_1\ Sm(S_F\{\Delta y_p\},\theta)\ e^{\sigma t}+\beta_2\ \Delta p_O\, e^{\gamma t}]^{\lambda} + c\, w(t-1) + w(t)\} \quad (7)$$

The result of identification and estimation for the resulted model is shown in the following tables

In this model the parameters such as t-statistics and R^2 improved. Inherent dynamic of system do not be able to behavior the output of the system electrical load demand.

Although the error has decreased but regarding all aspects the model is not acceptance. So the model needs more improvement.

Structure of the model is improved with entrance of two factors, purchase power of producer and consumer. Therefore the following model is suggested.

$$x_D(t) = S_F\{\alpha_1 x_D(t-1) + \alpha_2 x_D(t-2) + \dots$$

$$\beta_1\ Sm(S_F\{\Delta({}^{y}/p_{ID})\},\ \mu_1)\ [\ Sm(S_F\{\Delta y_P\},\theta)\ e^{\sigma t}\ ]^{\lambda_1} + \dots$$

$$\beta_2\ Sm(S_F\{\Delta({}^{y}/p_{HD})\},\ \mu_2)\ [\ \Delta p_O\, e^{\gamma t}\ ]^{\lambda_2} + c\, w(t-1) + w(t)\} \quad (8)$$

Regarding increased number of parameters (12 parameter) the identification is difficult so some of them is assumed constants includes

$\lambda_1 = \lambda_2 = 1$, $\theta = 15$, $\sigma = 0.05$, $\delta = 0.12$

The 6the model is improved.
The simulation of μ is not good but the results simulation gets better.
Poles are more stable. In the next step, it is assumed $\mu_1 = \mu_2 = 0.06$ *and* λ_i is free estimation result are shown in two-step of optimization Table (7).
Table (7) shows in infinite point, dynamic of system is not stable. And frequency increased.
Damping coefficient decreases from 0.2 to 0.1 but still the system unstable.
In figure (5) shows quality of simulation get better but projection for (2000) is not acceptable.

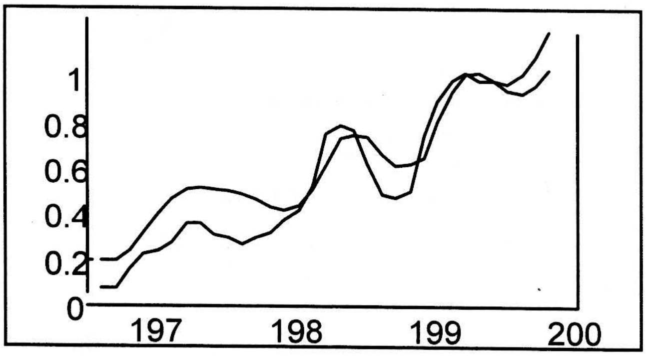

Fig. (5): Results of predication and simulation for 7 models

For determination of procedure for improving the model, real output and results compared. The difference is seen in period of [1984 to 1989and 1993 to 1995].

Because of the increase in the oil income in the years 1984 to 1986 and reduction of the war expense in these years, investment due to demand for electric power has risen. As usual, supplementary make up variables are used for explaining qualitative effects of these years. Although not limited to the supplementary variables, but because of the small difference between the two curves of the measurements and model output, these supplementary variables are considered as being comprised of 'zeros' and positive negative 'one'
Numbers.

μ_1 (t = 1984 till 1986) = 1

μ_1 (t = 1987 till 1989) = -1

Noting the logical seasonal combination of this function with the group of other functions, this input/entry has been added to the model as an addition to the right hand sentences of relationship (5).

In this case, the two parameters σ and γ, as before, have been assumed constant and respectively equal to 0.05 and 0.12.

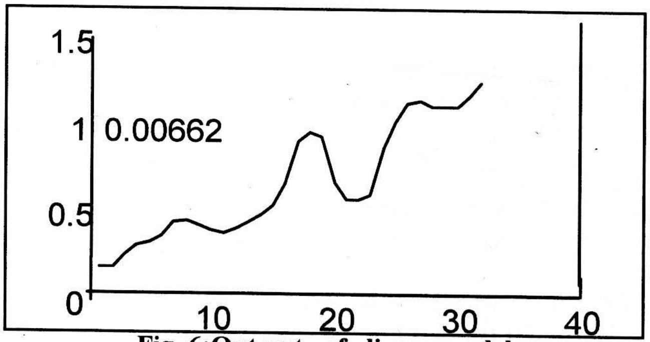

Fig. 6:Out put of linear model

Despite unapparent change in the frequency of oscillations have improved and
Are in line with the model's expectations.

Next step assumption to improving the model is $\mu_1 = 0.3$, $\mu_2 = 0.5$ result of estimation given by Table [9].

The improvement of structure of the model in next step is using of main smoothen input signals.

Result of estimation gained from [6] is given in table [10]. Overall characteristic of model is comparable in table too.

$$x_D(t) = S_F\{\alpha_1 x_D(t-1) + \alpha_2 x_D(t-2) + \ldots$$

$$\beta_1 Sm(\Delta(^{y}/p_{ID})\}, \mu_1) [Sm(\Delta y_P, \theta)\, e^{\sigma t}]^{\lambda_1} + \ldots$$

$$\beta_2 Sm(\Delta(^{y}/p_{HD}), \mu_2) [\Delta p_O e^{\gamma t}]^{\lambda_2} + \rho\, u_1(t) + c\, w(t-1) + w(t)\} \quad (9)$$

This clear that result is not much differed. This shows the model tolerate to uncertainty resulted. From measuring of Input and out put signals. Comparing Curves with the smooth shape approved this facet.

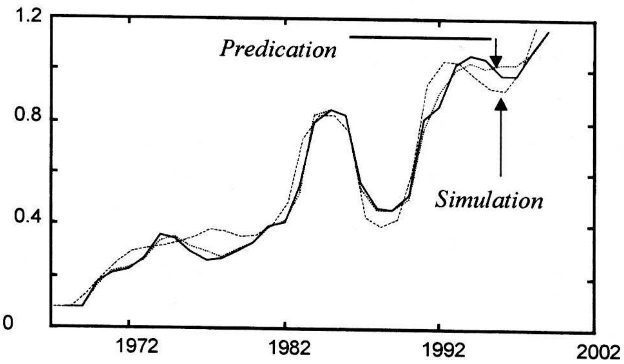

Fig. 7: Predication and simulation for load demand

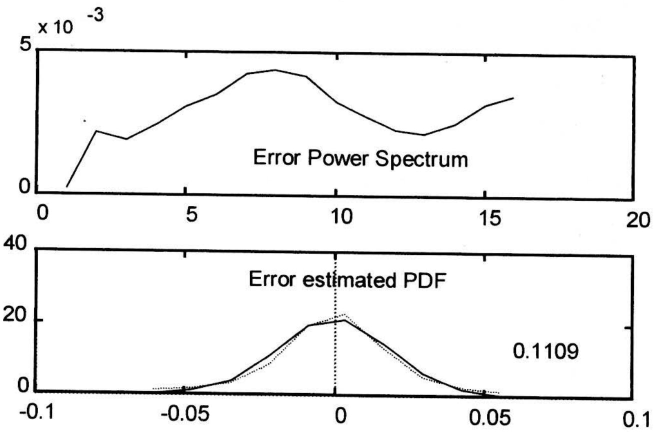

Fig. 8: Error function

For analyzing the situation of the dynamic characteristics it is enough to see the place of poles and step response. Figure [9] shows response steps and Figure [10] shows the place of one pole relative to linear model, nonlinear model [4] in unit circle.

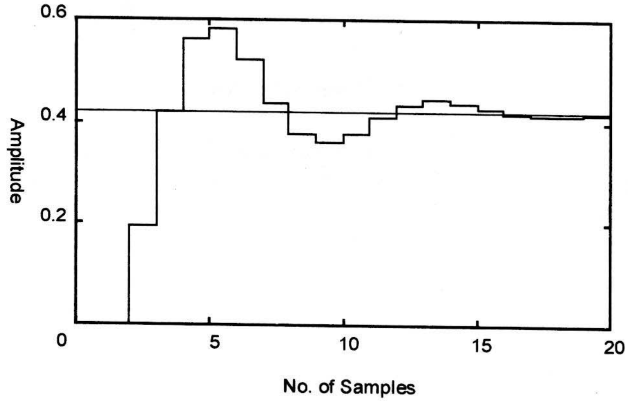

Fig. 9: Step response of model No 10 to the non-linear input

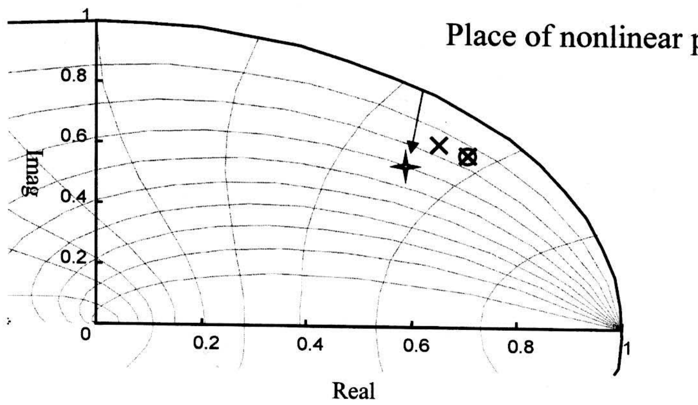

Fig. 10: Position of (one of) the poles of the non-linear star model No 10 compared with the previous models

The improvement in the results is expected in the sense that with increasing number of samples, the dynamic behavior of the model tends to have more stability. This may be due to change of dynamic behavior with time. In a system involving undeniable human interference, more stable behavior is expected as time passes because of increased familiarity.

Conclusions

By investigating various models of load demand, it was concluded that in linear models, although the relation between variables is clear, their inter-dependence exists. But in identifying the system's dynamic, and following the outputs for future years, difficulties exist.
Therefore, by noting the effect of saturation, and using profile functions and Sigmoid Functions, non-linear functions were approached. Besides identifying the system, the problem of the dynamic stability of the system is better estimated. Consequently, by using corrected non-linear model, the load demand model was identified.

NOMENCLATURE

$e_D(t)$: electrical load

$x_D(t)$: Derivative of electrical load

$u_i(t)$: input of system

y_P: income

P: Population

y: Production

y_N: non-oil – income

P_{ID}: price index of industrial equipment

P_{HD}: price index of residential equipment

P_{ED}: price of electricity

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[6] Statistical of Electrical Energy in Iran, Ministry of Energy, 1999

Table (1): Specification the best model

NO.	Numbers of Inputs				Whole determination	Error	R^2	GT	min(t-std)	Dynamic performance
17	1	3	2	2	.8648	.04789	.9660	33.71	1.0755	.8244
26	1	3	2	3	.8619	.04809	.9658	33.09	1.0546	.8196
8	1	3	2	1	.8594	.04764	.9661	31.79	.9518	.8374
161	5	3	2	2	.8540	.04774	.9661	31.44	1.0594	.8359
152	5	3	2	1	.8538	.04746	.9663	30.69	.9800	.8426
170	5	3	2	3	.8532	.04800	.9659	32.06	1.0896	.8257
5	1	2	2	1	.8484	.04876	.9653	36.21	.9645	.8328

Table (2): Results of estimation for the non-linear model No 2 with second degree dynamic and 9 parameters

Error: 0.0396			Explonatory: $R^2 = 0.9694$			Simulation: Fit = 0.9178		
α_1	α_2	β_1	β_2	λ	μ	σ	γ	c
-1.3796	0.8188	0.0908	1.5485	0.1044	0.6849	0.0569	0.1279	-1.0000
12.4294	6.9763	0.3509	0.7999	0.0929	1.2008	0.5414	3.3600	3.7982

Table (3): Results of estimation for the non-linear model No 2 with second degree dynamic and 7 parameters

Error: 0 .0417			Explonatory: $R^2 = 0.9703$			Simulation: Fit = 0.9204		
α_1	α_2	β_1	β_2	λ	μ	σ	γ	c
-1.3849	0.7876	0.1206	2.6521	0.8338	0.6093	0.0500	0.1200	-1.0000
15.6875	9.5621	3.0196	5.6509	0.8407	14.9043	Fixed	Fixed	7.1633

Table (4): Results of estimation for the non-linear model No 3 with second degree dynamic and 6 parameters, according to the relationship 6

Error: 0.0401			*Explonatory: R^2 = 0.9726*			*Simulation: Fit = 0.9262*		
α_1	α_2	β_1	β_2	λ	μ	σ	γ	c
-1.4101	0.8181	0.0854	1.8313	0.7131	0.6000	0.0500	0.1200	-1.0000
16.8341	10.5352	4.4934	5.4193	28.8371	Fixed	Fixed	Fixed	7.3988

Table (5): Results of estimation for the non-linear model, second degree dynamic and 6 parameters, according to the relationship 7

Error: 0.0067			*Explonatory: R^2 = 0.9954*			*Simulation: Fit = 0.6590*		
α_1	α_2	β_1	β_2	λ	μ	σ	γ	c
-1.7175	1.0000	0.0412	0.9407	0.6896	0.6000	0.0500	0.1200	0.7776
16.2152	11.0495	1.1271	3.1894	6.2652	Fixed	Fixed	Fixed	26.1652

Table (6): Results of estimation for the non-linear model, second degree dynamic and 7 parameter free, according to the relationship 8

Error: 0.0141			*Explonatory: R^2 = 0.9900*			*Simulation: Fit = 0.8651*			
α_1	α_2	β_1	β_2	λ_i	μ_1	μ_2	σ	γ	c
-1.2918	0.6466	0.1707	0.9452	1	0.4910	0.5881	0.05	0.1200	0.8021
7.5463	4.2193	2.3535	1.9574	Fixed	0.1694	0.1724	Fixed	Fixed	12.5395

Table (7): Results of estimation for the non-linear model, second degree dynamic, according to the relationship 8

Error: 0.0098			*Explonatory: R^2 = 0.9931*			*Simulation: Fit = 0.8056*			
α_1	α_2	β_1	β_2	λ_1	λ_2	μ_i	σ	γ	c
-1.4105	0.7601	0.1942	0.9595	0.6326	0.8880	0.6	0.05	0.1200	0.7623
-1.6008	0.8900	0.1179	1.1940	0.3334	0.8989	0.6	0.05	0.1200	0.7733
14.4727	8.4797	2.7951	3.3195	1.7042	3.1145	Fixed	Fixed	Fixed	17.4495

Table (8): Results of estimation for non-linear model No 8 according to Eqn (5) by

adding the ρ μsentence

Error: 0.0066			*Explonatory: R^2 = 0.9947*			*Simulation: Fit = 0.8782*			
α_1	α_2	β_1	β_2	λ_1	λ_2	μ_1	μ_2	ρ	c
-1.2057	0.6221	0.0536	1.3030	1.4414	0.5486	0.2748	0.4909	0.0922	0.7750
11.981	6.0357	0.6046	5.1891	1.2675	4.3189	0.9520	1.1831	6.7634	16.077

Table (9): Results of estimation for non-linear model No 9 according to Eqn (5) by adding the ρ μ sentence

Error: 0.0061		*Explonatory: R^2 = 0.9955*			*Simulation: Fit = 0.9411*		
α_1	α_2	β_1	β_2	λ_1	λ_2	ρ	c
-1.1546	0.6309	0.1771	1.3621	0.7402	0.6845	0.0767	0.7535
12.8526	8.1024	2.4783	5.2052	3.4436	4.0587	6.7327	15.8219

Table (10): Results of estimation for non-linear model No 10according to Eqn (9) by adding the ρ μ sentence

Error: 0.0069		*Explonatory: R^2 = 0.9949*			*Simulation: Fit = 0.9401*		
α_1	α_2	β_1	β_2	λ_1	λ_2	ρ	c
-1.1575	0.6211	0.1951	1.3847	0.6810	0.7464	0.0790	0.7558
24.0205	17.5820	3.2165	4.7790	3.9832	4.2838	6.2934	13.6607

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Evaluation of Interchange Capability under Open-Access Transmission

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Abstract: The evaluation of available transfer capability (ATC) is going importance in the restructuring of power sectors due to the increased interchange among utilities. Computing the ATC is a complicated optimization problem. State of the art techniques such as contingency selection and optimal power flow (OPF) should be integrated in order to implement the computation. This paper concentrates on the latter and shows a procedure for determining the interchange capability during the base case condition using an OPF. The OPF is specifically formulated for ATC assessment purpose and aimed at real time applications. A deterministic case is examined here.

Keywords: Available transfer capability, deregulation, open access, Optimum power flow.

1. Introduction

With the trend towards deregulation, there has been an increase in interchange transactions among utilities. As the power system becomes more heavily loaded, line thermal limit violations and voltage collapse phenomena may occur. The attention of planners and system operators turned to ATC issues because of concerns with network limitation and reliability. ATC refers to the capacity and ability of the transmission network to allow for a reliable movement of electric power from generation sources to customer loads. The ATC is dependent on network structure, contingencies and prevailing loading conditions. Computing the ATC is a complicated optimization problem requiring the integration of contingency selection and OPF techniques. Because of the stochastic nature of power systems behavior arising from random equipment outages and load variations, the determination of ATC should be in a probabilistic framework and performed during the planning stage. This paper focuses on a deterministic case called the base case condition and applies an OPF to obtain the interchange capability for this case. The OPF model is specifically used for ATC assessment purposes and its mathematical formulation is described. A case study of a modified IEEE 14-Bus test system with multiple electricity transactions will also be examined.

2. Outline of the procedure

A general procedure shown in figure 1 is used to maximize interchange capability while ensuring system security.

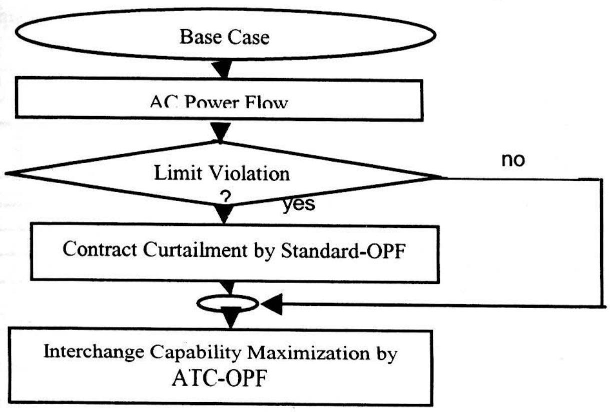

Figure 1. Evaluation Procedure of Interchange Capability

2.1. Ensuring Feasibility

A traditional AC power flow by Newton-Raphson method is initially used to check operational feasibility without limit violations. For instance, if the thermal limit is violated, a contract curtailment strategy is adopted to relieve network congestion and restore operational feasibility. The curtailment strategy used is based on a gradient-decent OPF algorithm [1] with weights of curtailment factors as introduced in Ref. [2]. The details of curtailment factors will be given in section 3.2. The objective is to minimize deviations from original contracted transactions while ensuring operational feasibility.

2.2. Maximizing Interchange Capability

At the end of the procedure summarized in section 2.1, the operating point has reached a feasible operating point, but possibly with some loads and transactions curtailed. A gradient-decent OPF algorithm whose objective is to maximize the interchange capability during the base case condition is implemented next. Lastly, an optimal power dispatch for maximizing the interchange capability can be obtained.

3. Mathematical Formulation

3.1. Transmission Dispatch with AC Power Flow

The power system consists of three parties, generation company (genco) as a power seller, distribution company (disco) as a power buyer and the Independent System Operator (ISO). A genco and a disco will enter a contract transaction at their own discretion and the ISO is only responsible for dispatching these contracted transactions while maintaining system reliability and making good transmission losses.The power injected at bus 1, P_1 is designated to make good transmission losses under an ancillary services contract between the ISO and the genco at that bus. Hence it is also designated as the slack bus during the power dispatch computations.

3.1.1 Individual Transaction

Let P_{ij} be the contracted power injected by genco at bus i, in pursuance of a transaction with a disco at bus j. So, let D_{ji} be the contracted power taken at bus j giving the following relationship:

$$P_{ij} = D_{ji}, \; i \in N_G; \; j \in N_D \qquad (1)$$

where N_G = a set of generation bus index excluded the slack bus
N_D = a set of load bus index

3.1.2 Group Transaction

A group transaction feature is added to represent the practical case of a utility whose generation plant and customers may be at various locations. The resulting group balance equation is:

$$\sum_i P_i^k - \sum_j D_j^k = 0, \quad \forall k \in N_k \qquad (2)$$

P_i^k = contracted active power injected at bus i in the k^{th} group
D_j^k = contracted active power taken at bus j in the k^{th} group
N_k = a set of group index

Note that it is assumed in this model that the system operator provides (and charges for) transmission losses.

3.1.3 Combined Dispatch by AC Power Flow

Combining (1) and (2), the active power P_i and D_j at generation bus i and load bus j are expressed in terms of the contracted powers as follows:

$$P_i = \sum_j P_{ij} + \sum_k P_i^k \quad (3)$$

$$D_j = \sum_i D_{ji} + \sum_k D_j^k, \quad i \in N_G;\ j \in N_D;\ k \in N_k \quad (4)$$

Therefore, given the contract information from gencos and discos, a set of specified variables $\boldsymbol{y}$ including generation powers and required loads can be determined. They are incorporated in the standard full AC load balance equations (5) and solved to obtain a feasible operating point $\boldsymbol{x}$.

$$\mathbf{g}(\boldsymbol{y},\boldsymbol{x}) = 0 \quad (5)$$

$\boldsymbol{y}$ = a set of variables which include $V_1, \theta_1, P_L, Q_L, P_G$ and V_G.

$\boldsymbol{x}$ = a set of unknown variables which include V_L, θ_L and θ_G.

V_1 / θ_1 = voltage magnitude/angle of slack bus

V_G / V_L = voltage magnitude of generation/load buses

θ_G / θ_L = voltage angle of generation/load buses

P_G / P_L = active power of generation/load buses

Q_G / Q_L = reactive power of generation/load buses

3.2. Contract Curtailment using OPF

If the system of equations (5) is not solvable for a given contracted setting $\boldsymbol{u}$ or there are operating constraint violations, a contract curtailment algorithm with weights of curtailment w is applied. The details of the curtailment algorithm can be found in Ref [2]. The w represents a participant's reluctance to contract curtailment for detailed competitive consideration. The basic concept is that the higher the "willing-to-pay", the less will be the curtailment of the transaction, which is a price lever in a competitive power market. The operating constraints including the line flow limit, voltage boundaries and generation capacities can be written as:

$$\mathbf{h}(\boldsymbol{u},\boldsymbol{x}) \le 0 \quad (6)$$

$$\boldsymbol{u} = \begin{bmatrix} P_{ij} & P_i^k \end{bmatrix} \quad i \in N_G;\ j \in N_D;\ k \in N_k$$

3.3. Interchange Maximization using OPF

The deterministic evaluation of ATC consists in maximizing the interchange capability of any selected contracted transactions during a base case condition (i.e. no contingency condition). The rest of unselected transactions that represent prior contractual constraints should remain unchanged. The problem can be formulated as:

$$\text{Max } f(\boldsymbol{u},\boldsymbol{x}) = \sum_{ij \in S} P_{ij} + \sum_{k \in S_k} \sum_{i \in S_{Gk}} P_i^k \quad (7)$$

subject to

$$\mathbf{g}(\boldsymbol{u},\boldsymbol{x}) = 0$$
$$\mathbf{c}(\boldsymbol{u},\boldsymbol{x}) = 0$$
$$\mathbf{h}(\boldsymbol{u},\boldsymbol{x}) \le 0$$

c = changes of interchanges of unselected contract transactions

S = a set of selected individual transactions whose interchanges are to be maximized

S_k = a set of selected group transactions whose interchanges are to be maximized

S_{Gk} = a set of selected generators in a group at which the injected active powers in the group is to be maximized

4. Solution Algorithm

The general problem is solved by the Gradient-decent method. The Lagrangian $\boldsymbol{L}$ to be optimized is:

$$\boldsymbol{L} = f(\boldsymbol{u},\boldsymbol{x}) + \lambda^T \mathbf{g}(\boldsymbol{u},\boldsymbol{x}) + c\,\mathbf{h}(\boldsymbol{u},\boldsymbol{x}) \quad (8)$$

and $$c\,\mathbf{h} = c_a \sum_{ij \in N_L} \mathbf{h}_1 + c_b \sum_{j \in N_B} \mathbf{h}_2 + c_c \sum_{j \in N_B} \mathbf{h}_3 \quad (9)$$

$$\mathbf{h}_1 = \begin{cases} (I_{ij}^2 - I_{max}^2)^2 & \forall\ I_{ij}^2 > I_{max}^2 \\ 0 & \forall\ I_{ij}^2 \le I_{max}^2 \end{cases}$$

$$\mathbf{h}_2 = \begin{cases} (V_j - V_{max})^2 & \forall\ V_j > V_{max} \\ (V_j - V_{min})^2 & \forall\ V_j < V_{min} \\ 0 & \forall\ V_{min} \le V_j \le V_{max} \end{cases}$$

$$\mathbf{h}_3 = \begin{cases} (P_j - P_{max})^2 & \forall\ P_j > P_{max} \\ (P_j - P_{min})^2 & \forall\ P_j < P_{min} \\ 0 & \forall\ P_{min} \le P_j \le P_{max} \end{cases}$$

where I_{max} = line current limit,

V_{max} / V_{min} = = maximum / minimum voltage limit;

P_{max} / P_{min} = maximum / minimum active power limit;

N_L = set of transmission line indices; N_B = set of bus indices

λ = Lagrangian multiplier; c, c_a, c_b, c_c = penalty factors

The gradient can be obtained as:

$$\nabla f = \left(\frac{\partial f}{\partial u}\right) + \left(\frac{\partial g}{\partial u}\right)^T \cdot [\lambda] + c \left(\frac{\partial h}{\partial u}\right) \quad (10)$$

5. Case Study

The procedure of evaluating the interchange capability during the base case condition is performed by using a test system in which the system is a modified IEEE 14-bus network with simplified busbar renumbering. The system has 14 buses, 20 tie-lines and 4 generators. Bus 1 being chosen as the slack bus is designated to make good transmission losses and is not involved in any transactions. Figure 2 shows this modified system diagram. The network details including the base-case operating condition, generation capacity and transmission line data can be found in [2].

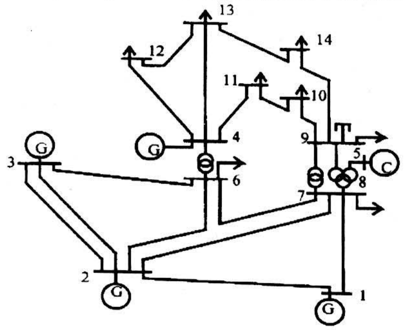

Fig.2. Modified IEEE 14-Bus System Diagram

5.1. Multiple Electricity Transactions

Suppose there are 3 individual transactions and 2 group transactions made by gencos and discos during a trading period.

Table 1 - Interchange Data

Transaction	Type	Requested Active Power Interchange (p.u)	
		Case 1	Case 2
3 – 6	Individual 1 (I1)	1.233	1.678
3 – 10	Individual 2 (I2)	0.153	0.190
3 – 13	Individual 3 (I3)	0.172	0.273
2 – 7	Group1 (G1)	0.848	1.029
2 – 9		0.357	0.548
4 – 9	Group2 (G2)	0.095	0.030
4 – 11		0.156	0.535
4 – 12		0.121	0.161
4 – 14		0.130	0.254