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Transmission Expansion Planning Based on Tabu Search Algorithm

Zakariya M. Al-Hamouz[1], A. H. Mantawy[1], Hussain Al-Duwaish[1], Ibrahim El-Amin[1], and Ali Al-Faraj[1]

Abstract. This paper presents a new approach for formulating and solving the transmission expansion planning (TEP) problem. The main improvement is in introducing the corona power loss in the objective function and operating constraints. This combination reveals a nonlinear objective function which is solved by Tabu Search (TS). The developed odel has been applied to Garver's 6-bus test sytem. When compared to previously reported TEP attempts, simulation results show a reduction in the total cost of the expanded network.

1. INTRODUCTION

The general form of the transmission expansion-planning (TEP) problem can be stated as follows, given: (1) the load-generation pattern at a target year, (2) the existing network configuration, (3) all possible routes (length and rights- of- way), and (4) line types, estimate the optimum network which feeds the loads with the required degree of quality and realizes a pre-specified reliability level.

To the authors' knowledge, all TEP approaches reported in the literature formulated their objective functions and the corresponding constraints to account for the cost of investment and/or the cost of ohmic power loss. In the literature, TEP has been solved by either optimization algorithms such as linear, nixed integer, quadratic, and nonlinear [1-4] or heuristic ones. Very recently, the Tabu search (TS) algorithm was applied to the TEP problem [5]. In this paper, a new formulation of the TEP problem in which the corona power loss has been added to the objective function is presented. A TS algorithm is utilized to minimize the objective function subject to the system constaints.

2. MATHEMATICAL MODELING OF TEP

In this paper, the authors propose a revised formulation of the objective function in which a new term, i.e. the cost of corona power loss, is considerd, in addition to the investment cost and cost of ohmic losses. The revised objective function and constraunts can be written as

Minimize:

$$\Sigma \text{ cost of investment} + \Sigma \text{ cost of ohmic loss} + \Sigma \text{ cost of corona loss} \qquad (1)$$

The cost of corona loss is expressed as [2]:

$$\Sigma \text{ cost of corona loss} = K_C \sum_{j=1}^{AD} \frac{CL_j \times l_j}{b} \qquad (2)$$

Electrical Engineering Department, King Fahd University of Petroleum & Minerals, e-mail: zhamouz@kfupm.edu.sa

$$CL_j(kW/km) = \sum_{m=1}^{3} 10^{\frac{CL_{jm}(dB)}{10}} \qquad (3)$$

$CL_{jm}(dB)=$

$$14.2 + 65\log\frac{E_{jm}}{18.8} + 40\log\frac{d}{3.51} + K_1 \cdot \log\frac{n}{4} + K_2 + \frac{A}{300} \qquad (4)$$

$$K_1 = 13 \quad \text{for } n \le 4 \; or \; = 19 \quad for\ n > 4 \qquad (5)$$

K_2 is a term that adjusts corona loss for rain intensity RI, and is given as [2]:,

$$\begin{aligned} K_2 &= 10 \cdot \log\frac{RI}{1.676} \quad , \quad for\ RI \le 3.6\,mm/h \\ &= 3.3 + 3.5 \cdot \log\frac{RI}{3.6} \quad , \quad for\ RI > 3.6\,mm/h \end{aligned} \qquad (6)$$

Where:

$RI = 1.676$ *mm/h*
AD : total number of lines added to the network
b : KW base
CL_j: corona power loss in the jth line (kW / km)
CL_{jm} : corona power loss in the mth phase of the jth line (dB)
d : diameter of sub-conductor (cm)
E_{jm} : rms electric field in the mth phase of the jth line (kV/cm)
K_C : cost coefficient of corona power loss (p.u. cost / p.u. power)
l_j : length of the *j*th line (km)
n : number of sub-conductors in a bundle

Subject to:

Power balance at each bus, Kirchoff's voltage law on each closed basic loop., Line flow, line height, phase spacing, & bundle radius constraints.

3. TABU SEARCH ALGORITHM FOR THE TEP

TS is an iterative improvement procedure in that it starts from some initial feasible solution and attempts to determine a better solution in the manner of a steepest-descent algorithm [5]. Since the variables in this problem are continuous in nature, using Tabu List (TL) needs some adaptation. In this work, values of variables stored in the TL are approximated to include only one-decimal place, to facilitate and ease checking of TL contents. For each variable, a TL of an array of size Z is constructed. Also associated with each TL is an array for the Aspiration Level (AL) of the same size.

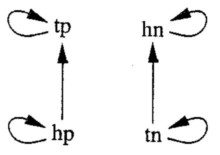

Figure 1. Point Set for *PAS*

Point	Intended Truth Value
hp	Necessarily true
hn	Necessarily not explicitly false
tp	True
tn	Not explicitly false

Table 1. Intended Truth Values in $\mathcal{P}$

2. The accessibility relations defined on $\mathcal{P}$: $R, R_\neg, R_{not}$, in which R is exhibited in Tables 2, and $R_\neg$ and R_{not} respectively in Figures 2, 3, such that an arrow from x to y denotes that there is an accessibility relation from x to y. As the reader can check, R is a plump 3-place accessibility relation, whilst $R_\neg$ and R_{not} are plump negative 2-place accessibility relations.

R hp hp hp	*R tn tp tn*
R hp hp tp	*R tn tp hn*
R hp tp tp	*R tn hp tn*
R tp tp tp	*R tn hp hn*
R tp hp tp	*R hn hp hn*

Table 2. Accessibility Relation R

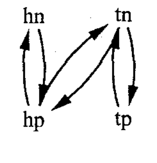

Figure 2. Accessibility Relation $R_\neg$

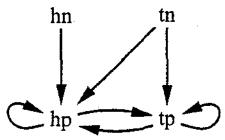

Figure 3. Accessibility Relation R_{not}

3. The (right) truth set of R is $\{hp, tp\}$, and corresponds to the truth constant **t** (see Definition 7).

The accessibility relations R, $R_\neg$ and R_{not} are obtained by adapting N-valuations used in [2] to present respectively the operators $\rightarrow$, $\neg$ and *not* into our frame to capture PAS^2. Alternatively, explicit negation could be treated in terms of a partial Kripke-style semantics as Pearce did. However, guided by Greg Restall's directions, we prefer to preserve the two-valued assessment applied to a two-dimensional frame. In the sequel some definitions handle the semantical part.

Definition 5 *By belief set, we mean* (S^p, S^n)*, in which* S^p *and* S^n *are sets of atoms. Thus, an atom A is true in* S^p *(resp.* S^n*) iff* $A \in S^p$ *(resp.* $A \in S^n$*); otherwise, A is false in* S^p *(resp. A is false in* S^n*).*

The knowledge ordering $\leq_k$ (see [4]) can be mimicked in a relationship involving belief sets as follows: let $B_1 = (S_1^p, S_1^n)$ and $B_2 = (S_2^p, S_2^n)$ be belief sets. The knowledge ordering $\leq_k$ among them is defined by $B_1 \leq_k B_2$ iff $S_1^p \subseteq S_2^p, S_2^n \subseteq S_1^n$. The mechanism behind knowledge ordering between belief sets is crucial to guarantee the expected definition of PAS. Pursuant to this aim, firstly we use $\leq_k$ to define HT^2-interpretations:

Definition 6 *A* HT^2-*interpretation is the pair* $[B^h, B^t]$*, in which* B^h *and* B^t *are belief sets satisfying* $B^h \leq_k B^t$.

Recalling frame $\mathcal{F}$, for each atom, a HT^2-interpretation can assign nine possible (truth) values corresponding isomorphically to the values found in the nine-valued logic IX (see [4]). To expunge any misunderstanding, we shall reserve the letters B and S to respectively denote belief sets and sets of atoms, using the notation $B^h = (S^{hp}, S^{hn})$ and $B^t = (S^{tp}, S^{tn})$. Now we are going to associate each S^x in $[B^h, B^t]$ to a $x \in Q$:

Definition 7 (HT^2-**model**) *Let* $w \in \{hn, hp, tn, tp\}$ *be a point of* $\mathcal{F}$, $M = [B^h, B^t]$ *be a* HT^2-*interpretation, "A" be an atom, and both* ϕ *and* ψ *be formulae. We say that* ϕ *is satisfied by M in w, written* $(M, w) \Vdash \phi$*, iff*

1. $(M, w) \Vdash A$ *iff* $A \in S^{wp}$
2. $(M, w) \Vdash \mathbf{t}$ *for all w in* $\{hp, tp\}$
3. $(M, w) \Vdash \phi \wedge \psi$ *iff* $(M, w) \Vdash \phi$ *and* $(M, w) \Vdash \psi$
4. $(M, w) \Vdash \phi \vee \psi$ *iff* $(M, w) \Vdash \phi$ *or* $(M, w) \Vdash \psi$
5. $(M, w) \Vdash \neg\phi$ *iff for each* w' *in* $\mathcal{F}$ *s.t.* $wR_\neg w'$, $(M, w') \nVdash \phi$
6. $(M, w) \Vdash$ *not* ϕ *iff for each* w' *in* $\mathcal{F}$ *s.t.* $wR_{not}w'$, $(M, w') \nVdash \phi$
7. $(M, w) \Vdash \psi \rightarrow \phi$ *iff for each* w', w'' *in* $\mathcal{F}$ *s.t.* $R\ w\ w'\ w''$*, if* $(M, w') \Vdash \psi$*, then* $(M, w'') \Vdash \phi$

M is a HT^2-*model of a theory T iff* $(M, hp) \Vdash \phi$ *for each* ϕ *in T.*

We say a HT^2-model $[B^h, B^t]$ of a program[3] P is *p-minimal* if there is no belief set $B' <_k B$ such that $[B', B^t]$ is a HT^2-model of P. The main result of this paper is shown below:

Theorem 1 *The p-minimal* HT^2*-models* $[B^t, B^t]$ *of a program P are exactly its paraconsistent answer sets.*

Considering paraconsistent answer sets embed both answer sets and stable models, our proposal is obviously eligible to deal with them. Answer sets can be defined by adding $hp \sqsubseteq hn$ and $tp \sqsubseteq tn$ to the point set of $\mathcal{F}$, and because of the conditions in Definition 2, we should also add new instances to $R, R_\neg$, and R_{not}. Similarly, stable models can be seen as answer sets versions free of explicit negation. The resulting frame is isomorphic to the one presented by Pearce [2] for answer sets (stable models). The main difference is that Pearce resorts to partial Kripke models to characterise answer sets, whilst we preserve the two-valued evaluation in each point (world).

3 Conclusion

We have defined a fully declarative approach for paraconsistent answer sets, by resorting to a frame based semantics. This is the first time a complete declarative characterisation is presented for paraconsistent answer sets, no syntactic transformation is used. Indeed paraconsistent answer sets are obtained by minimising models satisfying some conditions. Our proposal not only captures paraconsistent answer sets for extended disjunctive logic programs, but also models for any theory composed by formulae recursively definable for all program connectives. We have shown how one embed answer sets and stable models via frames.

Motivated by preliminary results, a general frame-based semantics to simultaneously capture both stable models and well-founded semantics families is expected in a following work. Finally, our proposal permits us to explore questions involving the role of logic programming semantics in the context of substructural logics.

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[2] In [2] N-valuations are used to determine Answer Sets.

[3] A program is a set of rules $L_1 \wedge \ldots \wedge L_l \wedge$ *not* $L_{l+1} \wedge \ldots \wedge$ *not* $L_m \rightarrow L_{m+1} \vee \ldots \vee L_n$, where each L_i is an atom or its explicit negation.