An Integrated Model for Transmission Sector using Cooperative Game Theory

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Abstract-- Restructured power systems require a separate model to analyze organizational, economic, operational and planning concerns in transmission sector of electricity markets. Grid operation in these markets is affected by violation of network operating limits, conflict of incentives and information asymmetry since commercial considerations overrule engineering needs. This paper proposes a model for transmission restructure that addresses these concerns and integrates the power business seamlessly. It incorporates market mechanisms to tackle network issues. A differential, elastic Transmission Service Charge (TSC) to reduce line loss and power deficit is presented and used as a coalition value to model transmission in a Cooperative Game Theory (CGT) environment. Counter-flow data is generated using graph theory based power vectors to resolve information asymmetry. The method was applied to a 24 bus Indian power system and gave a set of trades addressing above challenges.

Index Terms— Electricity Markets, Multilateral Trades, Cooperative Game Theory

I. Introduction

A. Challenge and Motivation

GAME theory, that analyzes actions of individuals affecting each other, has major applications in electricity markets [1-2] since power trades affect all market agents due to single grid configuration of the transmission sector. Grid operation is made complex by market games, network abuse, information asymmetry, incentive conflicts, profit compulsions overruling engineering considerations, etc.. Thus transmission is seen as an obstruction to development of fully competitive markets [3-4]. Strategies must evolve to protect the grid, central to power systems. Network usage can be optimized via cooperation of agents in a multilateral trade structure. Its other features are private economic data, high competition levels, separate decision and information structures, etc. [5-8]. Hence to model grid activities, CGT with well developed, mathematically sound theory on optimal and stable coalition formation among autonomous agents, is an ideal platform. CGT prescribes cooperation via repeated interaction in a multi-agent decision making context. Thus the challenge is to design a coordination scheme to have a concurrence of competitive and optimal trades and motivation is to retain the spirit and ideal concepts of a market in a multilateral market model.

B. Literature Review

Multi-disciplinary market models in literature focus mainly on allied issues only [9-13]. Separate models are proposed for analyzing organizational, economic, operational or planning aspects. But transmission models should be guided by power engineering since problem is ultimately operational. A widely implemented commercial trade structure, the Pool [14], with a powerful system operator, is accused to be a cartel and like the erstwhile system but with additional grid complexities. So, due to economies of transmission sector, it has to be regulated. One such mandated measure is 'Transmission open access'. But it leads to abuse of network when transacting trades of end-users, motivated by profit alone Transmission pricing poses some restraint. Past (embedded), present (operating & opportunity) and future (reliability & planning) cost of transmission services are allocated in economic models via many methods in literature [15-18]. But versatility of TSC in the special milieu of a market is generally not exploited. Another point of contention is that the fiscal prominence given to Gencos via decisive powers on energy charges and in TSC sharing makes the market arguably skewed. Also, shuttling of huge quanta of power on lines needlessly leading to voltage problems or fungibles when power is a commodity, are not given due attention in literature. In TSC designs emphasis is on congestion and loss allocation. Most proposals consider divisive measures like curtailment, congestion contracts, bid based transmission, etc. [5, 19, 20] to tackle congestion. They lead to destabilizing, collusive tactics from traders. Here, market mechanism approach is suggested to tackle all issue.

C. Approach and Contributions

Study conducted or challenges posed by [1-8] and solutions suggested vide [5-20] motivated a more holistic approach and a focus on market engineering to tackle issues. Market entity interactions are modeled in a unified CGT environment [21]. Two instruments based on market mechanisms were devised to aid the amalgamation procedure: a flexible TSC that checks network abuse and a power vector that resolves information asymmetry [22-25]. Power vectors are powerful intuitive tools computed using system configuration to identify partners, who through their own trades cause maximum counter-flows.

In the first phase, Discos (Distribution Companies) deal with Gencos (Generation Companies), compute and compare expected TSC with energy charges and analyze chances of collaboration. Next, Transmission Providers (TP) compute and allocate TSC for demanded transaction, conduct least loss iteration and release relevant TSC and power vector data. Discos use power vectors to negotiate agreeable TSC share. Successful coalitions are engineered to reduce combined TSC. This process continues till a grand coalition is reached or a socially stable set of coalitions are obtained. Social stability is crucial, since any retraction in real time is critical, both in security and commercial terms. Some major contributions are

1. Market engineering is used in a new fashion, assigning specific roles for each entity. A protocol is instituted such that one party cuts a cake most accurately and innovatively because the other gets the privilege to choose his piece. The model differs from its predecessors in giving prominence to Discos in financial maneuverings. Also, bidding, spot pricing and such non-cooperative measures are confined to Gencos and the complex transmission area is modeled in a CGT environment. A benefit of this strategy is that Gencos compete to reduce energy prices and Discos collaborate to get minimum overall TSC and thus maintain network security. So both energy and transmission charges are minimized.

2. TSC is devised as a flexible financial tool, strategically and functionally competent to coordinate trades. It penalizes abuse through a differential price mechanism and is elasticized with respect to demand. Thus TSC is suitable as a coalition value. A reduced TSC allocation acts as an incentive and interweaves the whole transaction operation. Such a versatile role and design for TSC is novel. Network impact is viewed as a consequence of confluence of all trades and so TSC is power flow based. Transmission prices evolve as a choice, based on market mechanism, and so reduces economic issues.

3. Transmission operation is also a matter of choice via a three phase coalition formation in a CGT environment. Power vectors guide the whole process. a concept not seen as applied to electricity markets, which is in dire need of tools to resolve information asymmetry. Fungibles are tackled in common information derivation phase of CGT. Design of payoff vector by modeling TSC sharing as a Socially Structured Transferable Utility (SSTU) game is a new technique applied with an endogenous power vector to test social stability (outside the scope of this paper). Planning signals are derived based on least loss iteration in the central information derivation phase of CGT to redress some planning issues.

The aim is to ensure network security as a common agenda. It is feasible in a CGT milieu, if agents sequentially aggregate with a sole motive, though their activities start at different functional and geographical locations in a power system. Some preliminaries of a CGT [26-27] atmosphere are given in Appendix. Unlike suggested by the terminology, ample room for competition exists in CGT, and parallels are drawn to the combinatorial in transmission sector in the method outlined.

II. Description of the Method

The problem is presented as an exercise to search out a set or combination of trades resulting in a minimum overall TSC. Based on these trades between market entities, the situation is interpreted as a generator rescheduling problem. These entities and some nuances of interactions between them that result in rescheduling are given. Ideas on how to employ market engineering techniques to embroil the entities in interactions that give rise to healthier trades are introduced. The procedure of identification of such trades in a CGT milieu and instruments helpful for their coordination are also given. First, the problem is mathematically formulated.

A. *Problem Statement and Solution Technique*

TSC ($p(q)$) is constructed to penalize loss, congestion and quantum of power shuttling over lines. DC line flow equations given below are used since TSC depends on flow in lines. For a power system model with n nodes, L lines, incidence matrix $\boldsymbol{M}_{Lx\ n\text{-}1}$, generation capacity of Genco at bus j is P_{Gj}, k_j is the fraction of power scheduled or injected at bus j , flow through lines z, primitive resistance matrix $\mathbf{R}_{LxL}$ and loss on lines q, if weights for penalizing loss, sum of power flow in all and congested lines are a (`/MW$^2$h), $b$ and $d$ (`/MWh) respectively and embedded cost is c, then

$$\mathbf{z} = R^{-1}M(M^TR^{-1}M)^{-1}k_j\,P_{Gj} \quad \text{(Line flow Eqn.)} \quad (1)$$

$$q = z^TR\,z \quad \text{(Transmission Loss Equation)} \quad (2)$$

$$p(q) = aq^2 + \text{b}\sum_L z + \sum_{congested} z + \text{c} \quad \text{(TSC)} \quad (3)$$

To model trades, factor $\mathbf{y}_{ji}$ is used to apportion P_{Di}, load of Disco at bus i to Genco on bus j. The problem hence is:

Minimize TSC subject to the constraints

$$\sum_{j=1}^{m} k_j\ P_{Gj} = \sum_{i=m+1}^{n} P_{Di} + q \quad \text{(Power balance Eqn.)} \quad (4)$$

$$k_jP_{Gj} = \sum_{i=m+1}^{n} y_{ji}P_{Di}\ , \quad \text{for } j\text{=2,m} \quad \text{(Trade Eqn.)} \quad (5)$$

A generator rescheduling problem based on trades collected by Discos is shown. Thus, solution is a set of trades resulting in minimum overall TSC. A set of optimal trades can be enforced by a central system operator by imposing restrictions on either the Discos or the Gencos. This makes the market more skewed and aggravates conflict of incentives. Hence a market solution is sought which coordinates trades, exploiting the particularities of an electricity market, dynamics within the market entities and strengths of a CGT environment.

B. *Market Dynamics and entities*

Gencos vie to capture market even by gambling energy prices. Then more Discos buy cheaper energy impacting the grid with loss, congestion, etc.. So end users make profit and abuse the network. In the absence of a centralized authority, TP as the custodian of the grid is the only entity who is concerned with the `runaway` on the transmission system. He can exercise control through a TSC that penalizes abuse. TSC design is fully based on ideas from market engineering and serves as an objective function. For minimization of TSC, TP alone has access to all transaction demand and should be entrusted the job of conducting optimization of generation, least line loss iteration, etc. for the published demand.

Making Discos accountable for payment of both Energy Charges (EC) and TSC will motivate Discos to optimize the sum of EC and TSC to be paid. Optimization is possible by reallocation of trades. In other words, cooperation among Discos empowers them to choose their Gencos and the power purchased from each Genco. This in effect reschedules generators, to obtain least impact on lines. A system operator of the Transmission Provider cannot reschedule generators, without being accused of affecting competition. Thus the fiscal role given to Discos enables them to collaborate and obtain more bargaining power with Gencos. Therefore, in the model, Discos play the game, to minimize the total charges paid as EC and TSC.

Thus distinct entities in the model are Discos, Gencos and the central TP. Gencos have influence over determining energy prices. TP is given the prerogative over construct of the TSC. Finally, the choice of determining who the supplying Gencos are and quantity of power purchased from each Genco will lie with Discos. This is a perfect emulation of interactions based on market engineering principles. Market mechanisms best resolve both information asymmetry and conflict of incentives in such tripartite interactions as is given next.

C. Entity Interactions

Network abuse minimization, is effective only as a joint venture in power markets, due to fungibles, counter-flows and because each trade affects all others. A coalitional game is proposed as the interaction. TP devises TSC to prevent line abuse. A finite set of players (here Discos) cooperate and obtain certain payoffs (here lesser allocation of TSC), as per CG with transferred utility. Coalitions that share this TSC must be socially stable. In a socially stable game no economic or social incentives exists for players to leave the game.

For a given social structure e.g. a network, a hierarchical ordering or dominance relation exists in any subset of players. A power vector defines this structure for every coalition, by reflecting the strengths of all its members. It was originally proposed [25] to measure positional power for application in tournaments and games. We develop power vectors to identify partners for amassing trades along the least loss route. In our scheme, directed graphs represent transactions in an electricity market. Vertices denote buses on which players of the game are stationed. Arcs with directions embody transmission lines and power flow through them. Player *i* is joined to player *j* to form the arc (*i,j*) if electric power flows from *i* to *j*. The positional power of each node is computed from its successors and their powers, as the function $\int p: \Lambda \rightarrow \check{R}n$ which assigns to every $\boldsymbol{A} \in \Lambda$. Here the vector $\boldsymbol{A}$ is a digraph with *n* nodes and arcs denoted $(i,j) \in A$; node *i* dominates *j* (successor).

$$\int p\,(A) = 1/n\,(I - 1/n\,T^{A})^{-1}\; s^{A} \qquad (6)$$

T^A is Adjacency matrix of A with elements, $t_{ij} = 1$ if $(i,j) \in A$, and $t_{ij} = 0$ otherwise, s^A is score vector (no: of successors)

Economic data is not shared in a market. Even divulged information is unreliable amongst competitors. In this context physical significance of power vector is that each Disco is able to identify one or more Discos, who through his own trade can influence maximum counter-flows in lines with respect to the assessor. This is because the method measures power of nodes as derived from both number as also power of its successors and subsequent successors. The power vector is a useful tool in all phases of a CGT game as is shown next.

D. Entity Interactions and CGT

Entity interactions are used to advantage in three phases of CGT as detailed below. The algorithm is shown in Fig.1.

1. Local Information Derivation and Computation Phase: In this phase Discos deal with Gencos and ferret out information regarding beneficial trades. Data used here are network configuration and tariff (constants *a, b, c,* and *d* in Eq.3) released by TP and bus data for Disco's own trades only. For any trade Discos can obtain line flows by load flow analysis (LFA), and loss, TSC and power vectors using above equations. Transmission is then demanded from TP. Node strength of other Discos is computed using outflows at each bus while conveying power from contracted Gencos to assessor Disco for his own trade. Data used is local, reliable, and Eq. 6 enables identification of the strongest partner.

2. Central Computation and Least loss Iteration Phase: In this crucial phase a large number of central data is generated. TP conducts a full LFA on receipt of all transaction demands and determines the overall TSC to be allocated among the Discos. TP computes line flows, loss, and power vectors for given trade combinations. Least loss iteration is performed and corresponding power vector is also computed and released. Derivation and allocation of TSC is also done simultaneously. Centrally released power vector exposes the least loss route, for the complete injection vector; is a part of the protocol devised for loss minimization and can be trusted by the agents.

3. Negotiation and Common Information Derivation Phase: Each agent, on receipt of allocation of TSC, attempts to reduce its impact via coalitions. In a large power system rationality prompts every agent to process its own data for identifying one or more collaborators. Power vector is an intuitive tool for Discos to seek partnerships in the wide web that is the power system. Larger the power of a partner, larger is its area of influence. Accordingly, invitations are floated from a preferential list and proposals are received. Mutual invitations are first processed and if the concerned parties can come to an agreement, further negotiations are made. In the negotiating phase, information derived by merging agents is common and is again reliable. Once the merger is finalized agents share common information including a new power vector, have a stable pay-off vector for TSC and a lower impact on the network. At this stage fungibles are addressed through allocation of loads via graph theory. They report back to TP or further coalitions are engineered, especially if a synchronizing agent emerges from amongst the participants. The end result is the finalization of a schedule of trades with least network losses. Data of a real system is processed as per the method given to check if the outcome is an optimal set of trades, next.

III. CASE STUDY

The Karnataka grid (India) in Fig.2 is used for illustrating the method. The given injection vector (total load of 1219.085 MW) and the resulting generator schedules are visualized as sets of trades. These trades incur a line loss of 36.36 MW. It is not the best situation on the network. Hence two searches are conducted at this stage. One is the least loss formulation and corresponding trades or Genco schedule, and the other is for the bus at which siting of generator results in best trades. The idea is to motivate Discos, vide a lower TSC to iterate trades to least loss condition via the three phases of CGT. Gencos can use the emergent 'generation expansion signal' on solving the siting problem. First, an initial set of trades are extracted through LFA and graph theoretical allocation, and assumed to be purchase intents of Discos. By grouping buses supplied by the same generator(s) Discos are formed as shown in Table I. Here we have five Discos deriving local information.

TABLE I
INITIAL TRADES OF DISCOS IN LOCAL INFORMATION PHASE

Bus No:	Load in Mw	Load share of Gencos located on Bus 1	Bus 2	Bus 3	Bus 4	Disco No:
6	70.244	70.08	-	-	-	I 187.3 MW
9	29.453	29.446	-	-	-	
10	87.819	87.81	-	-	-	
7	146.634	82.441	-	-	64.144	II 638.9 MW
11	34.351	0	-	-	34.352	
12	29.103	5.722	-	-	23.214	
13	146.2741	28.747	-	-	117.496	
16	224.236	112.651	-	-	111.549	
17	58.309	29.2999	-	-	29.013	
19	129.2957	21.129	108. 1625	-	-	IV 129.3
20	49.605	1.8315	9.326	37.403	-	V 142.8
24	93.194	54.717	7.514	30.115	-	
21	72.398	-	-	72.4	-	III 120.6
23	48.171	-	-	48.165	-	
Net	1255.445	562.591	125.00	188.08	379.768	MW

TABLE II
LOCAL INFORMATION OF DISCO I

Genco	loss {MW)	TSC ₹./hr x10^5	Power Vector of Discos I	II	III	IV	V
1	3.815	3.713	0.259	0.292	0	0	0123
2	16.138	29.709	0.264	0.335	0.084	0	0.082
3	8.273	11.339	0.262	0.330	0.083	.08	0
16	5.584	5.912	0.264	0.250	0.043	.04	0.082
Average TSC- ₹ 1.267 x 10^6 /hr							

1. Local information phase: In this phase Discos calculate allocable TSC and power vector based on line flow directions. Data used is locally generated and common data on network configuration and tariff (given in Appendix) for both TSC and power vector using LFA results of Disco's own trades. Several trade options may be comparatively considered. Some local information derived by Disco I is given in Table II. Similar data of other Discos are used or given in subsequent tables.

2. Central Computation Phase: For trade pairs viewed as purchase intents of Discos (Table I), total line loss is 36.36 MW and sum of power flow in lines is over 3825 MW. Total TSC is ₹14.36 million per hour. The enormity of this amount prompts a least loss iteration process by TP and a rethink on the part of Discos. The corresponding results including power vectors for both cases are shown in Table III. Then line loss drops to 15.43 MW; power moved over lines plummets to 2086 MW resulting in a TSC of ₹3.05 million/hr. From several allocation schemes, a division based on demands of Discos is made and given in Table IV. Average TSC as per local computations of all Discos, is also given. Clearly, Discos seek partners who cause counter-flows, enter negotiation phase and accordingly reconsider their intents.

3. Common Information and Negotiation Phase: Discos check local power vector in comparison with the optimal case. Considering the least loss case of Disco I (Table II), V has a power vector larger than 80% of the optimal case (Table III). Disco I invite V for negotiation who accepts (Table IV) since invitations are mutual. If they come to an agreement on pay-off vector, they merge and then move as a single unit. Similarly Discos II and IV reciprocate, collaborate and derive common information. Table V details this including the grand coalition.

TABLE III
CENTRALLY DERIVED DATA FOR TRADE INTENTS AND OPTIMAL TRADES

Purchase from Gencos in MW for intents and Optimal: Bus	intent	Opt.	Power Vector of all Discos for initial and final trades: No	intent	Opt.	80%
2	125	92.162	No	intent	Opt.	80%
3	190	192.218	I	0.311	0.323	0.258
4	380	28.064	II	0.531	0.411	0.329
16	-	439.531	III	0.137	0.140	0.112
loss	36.36	15.43	IV	0.090	0.092	0.074
power moved	3825	2086	V	0.137	0.140	0.112
TSC ₹/hr	14.36x10^6	3.046x10^6	net	1.206	1.107	0.885

TABLE IV
POWER VECTOR BASED NEGOTIATION USING TSC DATA

Disco	TSC in ₹./hr (x10^6) allocated	possible	Aver.	Negotiation phase First	Second
I	2.208	0.469	1.267	Invites V	Accept V
II	7.524	1.596	13.542	Invites IV	Accept IV
III	1.420	0.301	0.636	Invites I then II	Waits
IV	1.523	0.323	0.299	Invites I ,II,III	Accept II
V	1.682	0.357	0.479	Both I & II	Accept I

TABLE V
STEPS IN COALITION FORMATIONS AND MERGERS FOR OPTIMAL TRADES

Genco	Trade in MW when Discos merge: Dis. I & V	II & IV	II, III, IV	Grand coalition
2	51.16	73.386	127.376	92.162
3	48.413	32.605	143.804	192.218
4	2.579	31.036	31.237	28.064
16	69.544	364.588	369.987	439.531
Total	330.315	768.1528	888.662	1219.09
loss MW	5.217	6.533	8.909	15.43
MW moved	966.88 MW	1006.76	1288.7	2085.9
TSC in ₹/hr	0.617x10^6	0.729 x10^6	1.167 x10^6	3.046 x10^6
		Power Vector		
Disco I	.278	.259	.221	.323
Disco II	.248	.411	.453	.411
Disco III	.044	.123	.140	.140
Disco IV	.044	.048	.048	.092
Disco V	.140	.082	.085	.140
Decisions	waits; No preferences	First III, then I; I & V	Grand coalition gets best condition	

The most important phase is when units negotiate for an advantageous pay-off vector. Quite a lot depends on the bargaining power of the agents. Hence a pay-off vector derivation, based on the strengths of CGT, for example a marginal vector must be in place. In an electricity market any retraction in commitment in real time is going to be critical. Hence it is crucial that if not a grand coalition, a socially stable set of coalitions divide the TSC amongst them such that real time deviations are not there. In the example, in the grand coalition, a final optimal set of trades has been arrived at using graph theoretical allocation. This is the transaction demanded and is shown in Table VI.

TABLE VI
FINAL TRADES OF DISCOS IN THE GRAND COALITION

Bus No:	Load in Mw	Load share of Gencos located on Bus 1	Bus 2	Bus 3	Bus 4	Bus 16
6	70.244	40.232	-	-	0.106	29.897
9	29.453	16.869	-	-	0.044	12.536
10	87.819	50.298	-	-	0.132	37.377
7	146.634	27.192	-	-	15.949	102.356
11	34.351	-	-	-	5.501	28.459
12	29.103	-	-	-	0.998	28.034
13	146.2741	-	-	-	5.015	140.903
16	224.236	-	-	-	-	224.234
17	58.309	-	-	-	-	58.309
19	129.2957	45.344	83.953	-	-	-
20	49.605	2.582	4.831	42.165	-	-
24	93.194	60.313	3.378	29.484	-	-
21	72.398	-	-	72.399	-	-
23	48.171	-	-	48.117	-	-
Net	1234.515	260.25	92.162	192.22	28.064	662.106

III. RESULTS

The explicit results are

1. Reduction of line losses from 36.36 MW (3% of power transacted) to 15.43 MW (1.26%).
2. Total power moved over the lines comes down from 3825 MW (about 315% of demand) to 2806 MW (171%).
3. TSC per unit energy transacted for all Discos plummets to ₹2.50 from ₹ 11.78, the main factor compelling the Discos to come together to safeguard their own interests.

This is exactly the implicit outcome. The objective of TP is realized through the selfish motives of the marketers and is the reason to propose that only Discos play the game. Gencos already have their vested interests, in the form of energy charges. Discos are further motivated since their demands are not refused, but transacted at a lower cost. Gencos can make use of the generation expansion signals that was used to shift major generation from bus 4 and 1 to bus 16. Bus 4 requires only some fuel cell units. Bus 1, the slack bus may be controlled by TP for more flexibility.

IV. CONCLUSION

It has been shown that the three phases of CGT can successfully coordinate multilateral trades with the help of two instruments - an adequately designed TSC and a power vector. These results are important because transmission sector is the most difficult zone to model in an electricity market due to several issues and this model addresses concerns of abuse, asymmetry and conflicting motivations. The model is most relevant when transmission also becomes competitive. In an electricity market, such market engineering techniques find more applicability, suitability and even acceptability. All contributions are based on market mechanisms. Some extensions to this work are completed and include derivation of the solution space and the socially stable core of the game. TSC can be refined further for regional adaptability.

APPENDIX

Expert Procedures induct local priorities into TSC for choosing weights for Eq. 3 but are applicable only in practice. Here selection of criteria and weights is done based on rulings from Central Electricity Regulatory Commission's (India) and central objective of loss minimization. An average of wheeling charges of ₹ 60/ kW/month or ₹ 60,000/MW/month for *b*, amounting to ₹ 250/MWh Double this value- ₹ 500/MWh is chosen for penalizing congestion through *d*. *a* is assessed on par with energy charges of ₹ 10/- per unit, taking the weightage to ₹ 10,000/MWh. *c* is ignored.

A. Cooperative Game Theory

Cooperative games [27-28] focus on formation of coalitions and describe only outcomes, when players come together in different combinations. CGT embodies not just cooperation but competition in a strong, unfettered form and is better termed combinatorial game theory. Some definitions are

1. In a cooperative game, a finite set of players, $\boldsymbol{N}$=1,2,3...n form coalitions to earn a benefit or coalition value $\boldsymbol{v}$. Typical value created when members of S, subset of N, come together and interact is denoted $\boldsymbol{v}(\boldsymbol{S})$. So, a cooperative game is a pair $(\boldsymbol{N},\boldsymbol{v})$, where $\boldsymbol{v}$ is a function mapping subsets of $\boldsymbol{N}$ to numbers.

2. In a game $(\boldsymbol{N},\boldsymbol{v})$, $\boldsymbol{v}(\boldsymbol{N})$ specifies overall value created. A pay-off vector/allocation is a collection of numbers, $(\boldsymbol{x}_1,\boldsymbol{x}_2,..\boldsymbol{x}_n)$ obtained by dividing overall gain created. Quantity $\boldsymbol{x}_i$, denotes value player $\boldsymbol{i}$ receives. CGT seeks equity and fairness and permits splitting gains from cooperating in coalitions.

3. Coalition is a foundational agreement that binds and reconstitutes individuals as a coordinated entity for $\boldsymbol{n}$ members with $2^{\mathbf{n}}$ possible coalitions and $\boldsymbol{N}$ as the grand coalition. Thus coalitions are non-empty subsets of players.

4. An allocation is individually rational if $\boldsymbol{x}_i = \boldsymbol{v}(\{i\})$ for all $\boldsymbol{i}$. It means allocation of overall value gives each player as much value as he receives without interacting with other players.

5. An allocation is efficient if it satisfies group rationality.

6. Marginal contribution of player $\boldsymbol{i}$ is $MC_i = \boldsymbol{v}(\boldsymbol{N}) - \boldsymbol{v}(\boldsymbol{N} \backslash \boldsymbol{i})$, meaning the amount by which the overall value would shrink if the player in question were to leave the game.

7. An individually rational and efficient allocation satisfies the Marginal contribution Principle if $\boldsymbol{x}_i = MC_i$.

Marginal Contribution Principle formalizes an intuitive line of reasoning in bargaining and offers a method of analysis of division of value. Sellers try to play one buyer off against another and buyers do the same. A player's 'bargaining power' will depend on the extent to which he needs other players compared to their need for him. Thus CGT shows exactly, effect of competition in a bargaining situation. It makes precise the idea that division of value should reflect who needs whom more. But the analysis of how residual value will end up is agnostic. Final outcomes would depend on 'intangibles' such as how skilled players are at persuasion, bluffing, holding out, etc.. Thus indeterminacy in the theory at this stage is a virtue and not a vice. It is the possibilities for coalition formation, at once promising and threatening that are decisive in negotiations and choice of strategies.

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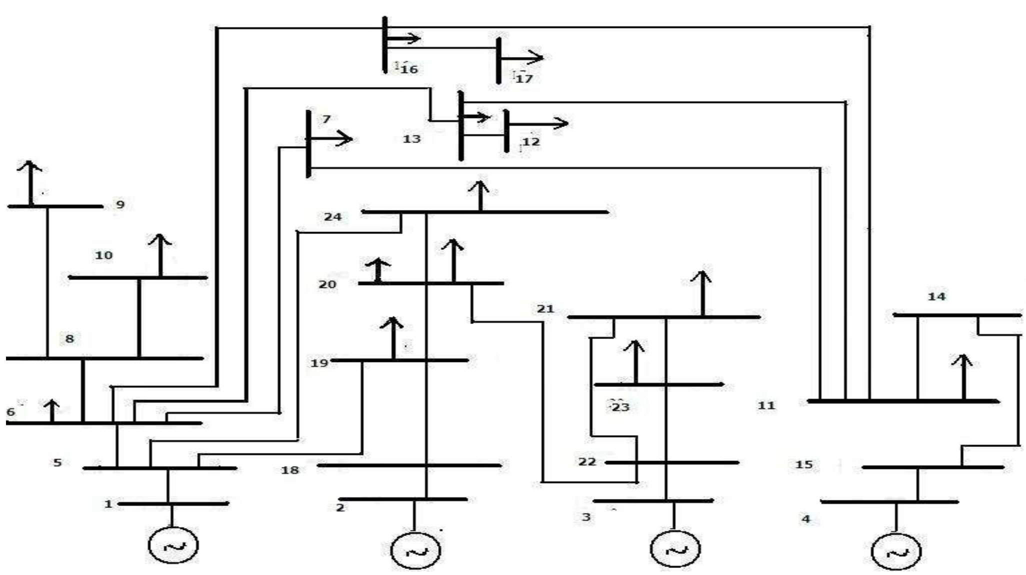

buses connected		line Resistance (pu)	Bus No:	MW Load / gen.
1-5	T1	.00069	1	slack
2-18	T2	.00348	2	125
3-22	T3	.0028	3	190
4-15	T4	.0014	4	380
5-6	a	.0045	5	0
5-19	b	.01263	6	-70.244
5-24	c	.02494	7	-146.634
6-7	d	.03716	8	0
6-8	e	.01239	9	-29.453
6-13	f	.05169	10	-87.819
6-16	g	.01530	11	-34.351
7-11	h	.02444	12	-29.103
8-9	i	.00363	13	-146.2741
8-10	j	.00330	14	0
11-13	k	.00314	15	0
11-14	l	.00063	16	-224.236
11-16	m	.00495	17	-58.309
12-13	n	.01321	18	0
13-16	o	.00578	19	-129.2957
14-15	p	.00430	20	-49.605
16-17	q	.00248	21	-72.398
18-19	r	.00537	22	0
19-20	s	.01131	23	-48.171
20-22	t	.01734	24	-93.194
20-24	u	.01982		
21-22	v	.00330	BUS DATA	
22-23	w	.03633		

Fig. 1 Karnataka grid- 24 Bus power systems (Typical Indian radial system)

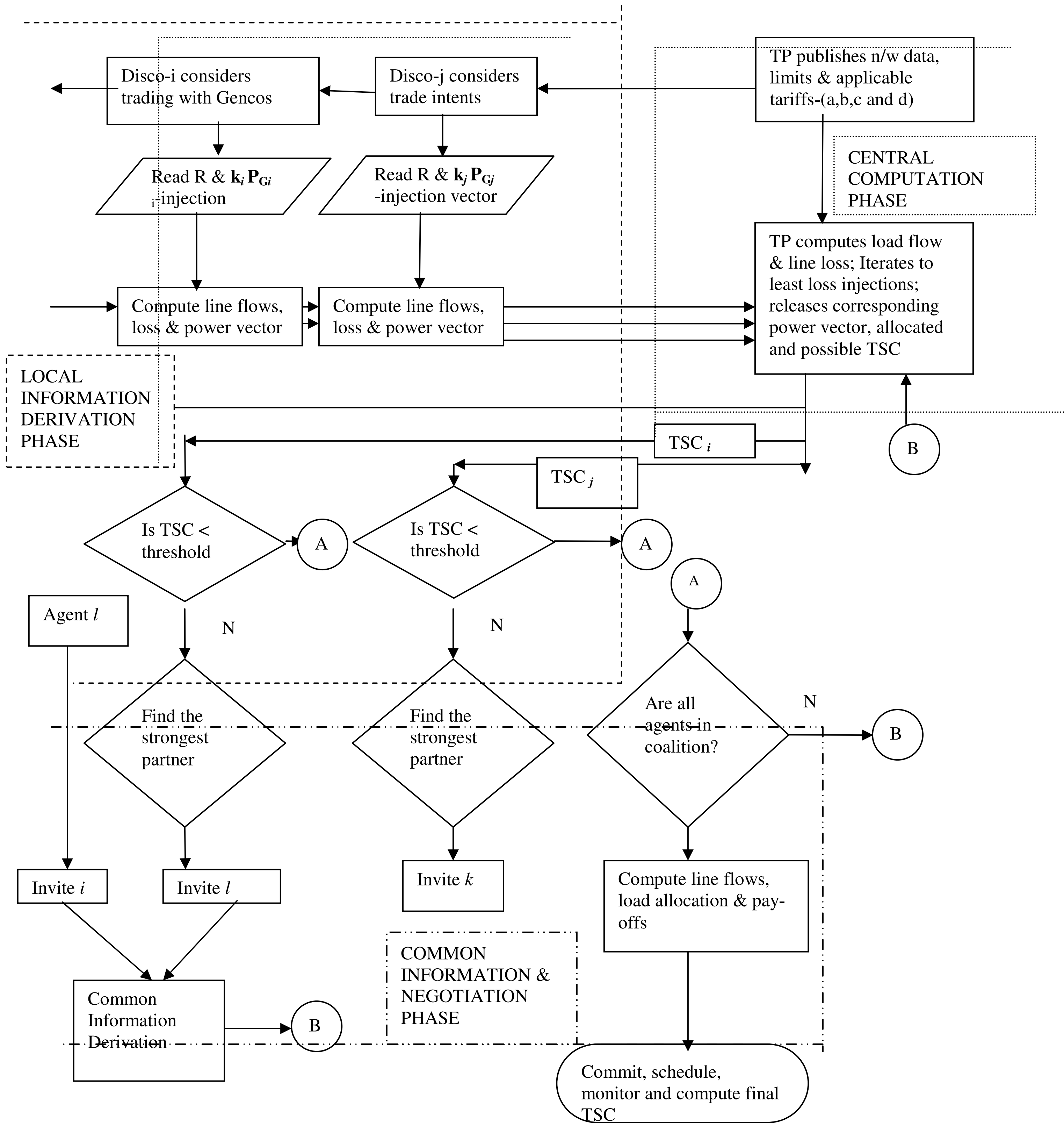

Fig.2 Central Proposal for coordinating least loss multilateral trades via power vectors, TSC through 3 phases of CGT