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A bottleneck-free bidding zone configuration approach qualification

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Nodal or zonal price signals are generated in a power network based on prevailing market philosophies. In nodal pricing regime, prices are derived at each injection or withdrawal node. These prices will vary across the network based on congestion and losses in the network. In financial market context, network is considered to be lossless. Thus, occurrence of congestion in the network creates different prices for electricity transactions. This is known as bottleneck issue. However, in zonal pricing regime, the complete network is present as a single zone in the absence of any bottleneck. In practice, market splitting takes place in presence of bottlenecks in the network. This is an attribute of power market that has been adopted in decentralized market clearing practice, the example of which are Indian power market and Nordic pool. The market splitting is done based on pre-specified zones that are fictitious and formed based on regulator's experience. These zones are termed as copper plate in which all players are treated on par as they are connected to a single bus having a single price for buying and selling of power. It is expected that players enjoy enough market liquidity and risk hedging to play freely within a zone to have perfect competition. In India, these zones are formed based on geographical and political boundaries. This might bring the players who are non-contributors of congestion into the wing of high price zone. This creates an issue of fairness. This paper proposes a methodology to solve network segmentation problem in wholesale competition environment so that appropriate bid areas are formed. A two-step process is proposed. Firstly, an optimization based zone formation of nodes with closeness as a decision index is done. Secondly, a fine adjustment on the results of the first step by bus migration process is done. The proposed method is implemented on modified Indian power network consisting of 193 buses, 452 branches and 52 generators. It is observed that a clear-cut and practically implementable bidding zones are formed using this method.

Keywords: *Bidding zones, electrical distance, network partitioning, differential evolution algorithm*

1.0 INTRODUCTION

The deregulation in power system has gone through unprecedented changes from its inception. The electricity is now looked upon as a commodity to be sold and purchased like any other commodity in the market. However, the nonstorable nature of electricity distinguishes itself from other commodities. Thus, electricity has to be generated at the time of its need. Due to this very nature of electricity makes the prices volatile for its usage, hence, huge risk is involved in this business. Therefore, the buying and selling of electricity is done at three stages: bilateral-contract, day-ahead and realtime. Among these three stages, the day-ahead market is most crucial

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as both buyers and sellers become more certain about their requirements, thus, provide sufficient opportunity for both to make profits. However, the physical limitation of transmission network impedes the smooth operation of the market and leads to congestion in the network. This creates a bottleneck in the network.

In the centralized market, the congestion alleviation is achieved at one go because of the single entity handling the role of market and system operator. Also, the nodal prices are aggregated to form price zone or hub [1]. Whereas, in decentralized market, two different entities are assigned for the role of market and system operators. In decentralized market, like India, the introduction of power exchanges has led to a thought provoking process on various issues including network segmentation. As per the current practices being followed in power exchanges in India [2], pre-defined zones are formed, which are called as bidding areas. These areas are formed according to the ownership of various state utilities, sometimes combining two - three utilities' grids to form a bidding area. While forming the bidding areas, the most obvious looking transmission bottlenecks are considered and these demarcate the boundaries. Apparently, the zone formation is done in ad-hoc fashion, in the absence of any formal, elegant approach to demarcate appropriate zones across bottleneck. In decentralized market, market operator collects the bids from the buyers and sellers. After performing the market settlement, the schedules are passed to the system operator for approval. System operator imposes the schedules in the network and performs power flow to get the line flows. On violation of any line flow limit, system operator signals to the market operator about the violation. Thereafter, market operator initiates the market splitting mechanism to avoid this congestion in the network. The market splitting mechanism segregates the network into two pre-specified zones across the congested line. Again, market settlement is done for both the zones separately and the schedules are given to the system operator for the checking of any violations. This process is repeated until all the violations are eliminated. The buses present in the zone appearing in the upstream of the congested line, experience the lesser electricity prices in comparison to the buses in the zone appearing in the downstream of the congested line. Thus, it is important to form zones in the most efficient manner.

Network segmentation is an application oriented problem. The complexity of the problem increases for a large interconnected power system. A rudimentary but intuitive way of network segmentation for large interconnected power system having multiple owners is to demarcate the boundaries as per ownership of the control areas. Since control area was the same as ownership area, the commercial settlements were easy between the areas. Thus, artificial boundaries without respecting the parameters and variables associated with power system were created. This worked well so long as markets were not introduced and power exchanges were absent.

In different European pools, various philosophies are adopted to impede congestion and provide payback for generation adjustments are mentioned in [3]. An study to identify various potential zones, i.e. load pockets, having approximately equal LMP, subject to technical and operational constraints is performed in [4]. Based on the data records of pre-cluster for the formation of price zones, two step clustering of nodes based on mean index adequacy and clustering dispersion index is presented in [5]. The tearing of graphical electricity network into the formation of zones is conceptualized in [6] and [7] which is known as diakoptics. Further, the concept of diakoptics is implemented for the reduction in computational efficiency of large scale systems by data clustering is presented in [8]. Additionally, its application for the operation and control in a large interconnected power system is given in [9]. An evolutionary algorithm based partitioning of the power network assuming the partial derivatives of all active power with respect to the angle of voltages as electrical distance that generates different cluster pattern depending on cohesiveness indices is presented in [10].

The combinatorial problem of cluster formation is categorized as NP-hard type problem. Therefore, metaheuristic based clustering techniques and their different essence is summarized in many literature [11]. A two-step controlled islanding algorithm for the minimum power flow disruption is implemented using spectral clustering that produces groups of coherent generators using their dynamic models in [12]. In [13], a similar problem is explained with the implementation of hierarchical clustering that represents internal connectivity of network, spectral clustering, using given values for the network splitting. A comparison of unsupervised clustering algorithms such as K-means, fuzzy K-means and hierarchical clustering for the consumer pattern based on specific tariff structure is stated in [13]. A centroid model for customer partitioning approach on the basis of load pattern of their consumption based on ant colony clustering algorithm is presented in [14]. The disintegration of power system into smaller nodes supports the power engineers in their operational and planning studies such as load profiling, islanding, blackout, spinning reserve, security assessment and voltage control. In [15], a similarity matrix based system partitioning and reduction for accuracy improvement with negligible increase in simulation time is proposed. Available Transfer Capability (ATC) is considered as similarity matrix in spectral clustering for the error reduction in line flows, costs, prices, and losses. A controlled islanding algorithm to minimize the power flow disruption by constructing a graph based on constrained spectral clustering in real time is presented in [17]. Edge weights are evaluated based on transmission line availability and coherent generator groups using a subspace projection.

This paper proposes a methodical two-step approach for network segmentation using optimization based clustering in the first step and then fine readjustment of the same using zonal participant migration in the next step. The second step is inspired by the concept of 'incentive compatibility' whose possible outcomes generate at least one equilibrium that satisfies the social choice rule [18]. Aim of this segmentation is to carve out bidding areas so that each bus in that area is deemed to possess the physical properties of that respective area. This segmentation helps in invoking the price area congestion management technique [19], typically used in power exchanges in India. The LMPs obtained from Optimal Power Flow (OPF) are employed to establish the group of buses exhibiting similar properties.

The rest of the paper is arranged as follows: Section 2.0 describes objectives and modeling of the problem. Section 3.0 explains the flow index that recommends the need for intercluster nodal shift along with two-step algorithm. Also, differential evolution algorithm for the network segmentation is explained. Section 4.0 discusses the results and the conclusion is provided in section 5.0.

2.0 MODELLING

Lagrange multipliers are the by-product of the Optimal Power Flow (OPF) problem. These multipliers are associated with all the equality and inequality constraints of the OPF problem. Among all these Lagrange multipliers, those associated with the nodal real power balance constraint are termed as nodal LMPs (Locational Marginal Prices). The LMPs may vary across the nodes in the system on account of congestion and losses in the system.

For the choice of similarity measure between the nodes, LMP appears to be an obvious and logical representation. Especially, when zones are formed by virtue of transmission bottlenecks, selecting LMP as a similarity measure does make sense. The motive of zone formation can be linked with the characteristics of LMP of each bus. The zones formed will have buses with closer LMP values can be aggregated as price zones. Creation of these price zones are based on two main conditions: LMPs on the buses within these zones are within a range and significant LMP difference exists between LMP of different zones. Thus, the difference in LMP of the buses within zone demarcates the network into price zones.

The graph segmentation problem can be defined for n nodes or vertices V and set of edges E linking the vertices having some standard distance between all pairs of vertices, $\lambda_{ab} \forall (a,b) \in V$, as a method to divide all vertices V in exactly N sets $\{C_1, C_2, ..., C_N\}$ where $(C_i \subset V, C_i \cap C_j = \emptyset)$ and N is the number of clusters, such that the distances between the sets are maximized and the distances within the sets are minimized.

LMP obtained from OPF solution is processed into quality indices to be utilized in the formation of zones as given in [10]. These indices evaluate the cohesiveness between nodes within clusters and penalize the deviation of the formed number of clusters from a prescribed value and, also, for the irregular formation of cluster size. Additionally, it maintains the connectedness for all nodes within clusters. However, the approach in [10] is based on "electrical distance" indices. We have replaced the "electrical distance" indices with the 'LMP separation' indices. This is because the application of segmentation that we intend to do, is in congestion management, by pre-defining bidding areas. For this, the LMP preparation provides best measure to assess the zone creation on account of transmission bottlenecks. The electrical distance is rather remodeled as LMP obtained for each node from the AC-OPF in these normalized indices as $\lambda_{ab} = |\lambda_a - \lambda_b| \forall n$.

2.1 Electrical Cohesiveness Index (ECI)

This index evaluates the intensity of within cluster cohesiveness among each nodes in the cluster in consideration. Equation (1) approaching *one*, a highly cohesive cluster, explains that the LMP of the nodes in the cluster does not differ much and can be allocated under single control center.

$$ECI = 1 - \frac{\sum_{a=1}^{n} \sum_{b \in C_a} \lambda_{ab}}{\sum_{a=1}^{n} \sum_{b=1}^{n} \lambda_{ab}} \quad ....(1)$$

2.2 Between Cluster Cohesiveness Index (BCCI)

This index is an extent of least cohesiveness between a node and the nodes of other clusters. Equation (2) reaches towards *one*, demonstrates the maximum difference in the LMP between the nodes in different clusters.

$$BCCI = 1 - \frac{\sum_{a=1}^{n} \sum_{b \notin C_a} \frac{1}{\lambda_{ab}}}{\sum_{a=1}^{n} \sum_{b=1, a \neq b}^{n} \frac{1}{\lambda_{ab}}} \quad ....(2)$$

2.3 Cluster Count Index (CCI)

This index keeps the number of clusters at most to a prescribed value, N^*. It approaches *one* if the number of clusters is equal to N^*.

$$CCI = \exp\left(-\frac{(\ln N - \ln N^*)^2}{2\sigma^2}\right) \quad ....(3)$$

2.4 Cluster Size Index (CSI)

This index maintains the size of each cluster to remain as close to the equally sized clusters, $S^* = \frac{n}{N^*}$, with the prescribed value of number of clusters. It approaches *one* when the cluster size is equal to S^*.

$$CSI = \exp\left(-\frac{\ln\left(\sum_{i=1}^{n} \frac{S_i}{n}\right) - \ln S^{*2}}{2\sigma^2}\right) \quad ....(4)$$

is equal to $\omega \ln(n)$ in equations (3) and (4) where ω acts as penalty factor that increases with the number of clusters going away from N^*. This paper uses $\omega = 0.05$.

2.5 Cluster Connectedness (CC)

A graph is divided into clusters such that the each node in the cluster is directly connected to at least *one* node of the same cluster. This is necessary for the control center to operate in its zone without infiltration into other zones. This binary index will be either *one*, complete connectedness, or *zero*, non-connectivity of nodes within cluster.

2.6 Aggregate cluster fitness

The indices discussed above are modeled as a multiplicative aggregate fitness function with an individual weight, $\{\alpha,\beta,\gamma,\delta\}\in[0,1]$, for each indices.

$$\text{Max. } f = ECI^{\alpha}\times BCCI^{\beta}\times CCI^{\gamma}\times CSI^{\delta}\times CC \quad ....(5)$$

Maximization of equation (5) will provide suboptimal demarcation on areas having adequate difference in LMPs. However, particularly due to CSI, equation (5) tends to form clusters of nearly equal sizes which is also necessary. There is a possibility of losing some of the efficient zone formations that might be achievable by shifting few nodes into the neighboring areas. In the next step, we fine adjust the results obtained. If segmentation obtained in the first step is believed to be appropriate, the balanced nodal perturbation inside a zone should impact the line flows within that zone the most, with less impact on lines outside that zone. Thus, the following condition should be satisfied for dominant number of cases:

$$\frac{\partial P_{lm}}{\partial P_i^j} > \frac{\partial P_{xy}}{\partial P_i^j} \;\; \forall \;\; lm\in S, xy\in T$$
$$\forall \;\; i \,\exists\, C_j \text{ for } j=1,..,N \quad ....(6)$$

where, P_{lm} and P_{xy} are the line flows, S is the set of lines within cluster j, T is the set of lines outside cluster j and j is the cluster under consideration.

The very fact that condition equation (6) is grossly violated, indicates that there is large scope for further fine adjustment of the results. This is envisaged in second step; explained in later section.

3.0 APPROACH FOR TWO STEP NETWORK SEGMENTATION

Some of the difficulties faced with the traditional techniques (i.e. K-means, spectral and hierarchical techniques) are as follows:

(a) Nodes within clusters cannot be traversed at times.

(b) Maximizing and minimizing the distances for inter and intra-cluster are not done optimally and may generate a suboptimal solution.

(c) A solution with degraded CSI is formed.

To tackle these issues, an integer based cluster formation in [10] is implemented and optimized by Differential Evolution (DE) algorithm. This algorithm is as follows.

3.1 First step: Optimization based clustering

DE is a powerful tool for obtaining optimal solutions. Stepwise explanation for its utility is as follows.

3.1.1 Initialization

Each target vector, *TV*, will be a vector having length of *V* with a lower bound as *zero* and upper bound as *E* connected to that vertex. Each edge is numbered with respect to each node for the formation of different cluster sets. Different *TV* are generated for a *priori* set population size, *M*.

3.1.2 Formation of clusters from each TV

Diakoptics based cluster formation is done to form a genotype in a set of phenotypes. Indices and *f* are evaluated for each *TV*. The best *f*, f_{best} and corresponding *TV*, TV_{best}, is stored.

3.1.3 Mutation

There are five different mutation operators proposed in [20]. In this paper, mutant vector, *MV(r)*, is equal to $TV(r_1)+F_1(TV(r_2)-TV(r_3))+F_2(TV(r_4)-TV(r_5))$ where r_1 to $r_5\in\{1,\ldots,M\},\notin r$ and F_1 and F_2 is varied in small steps between *0.8* to *0.3* and *0.6* to *0.2*, respectively.

3.1.4 Trial Vector

MV generated in the previous step is replaced with the corresponding *TV* on the basis of a probability, *CR*, generating group of vectors known as trial vector. This paper uses *CR=0.8*.

3.1.5 Selection

A concatenated matrix of *TV* and trial vector is formed, sorted and squeezed to first *M* vectors, on the basis of *f*, as new *TV* for the next iteration.

3.2 Second step: Fine adjustment by zonal participant migration

The optimal cluster, TV_{best}, formed from the first step is utilized in this step for further improvement by zonal participant migration. This is done in order to check if there is further room to improve TV_{best} such that the operational properties of clusters are best served. Ideally, clusters formed are said to be appropriate if the perturbation within the cluster affects the variables within the cluster, the most. A social choice rule based on node migration is invoked to check the appropriateness of clusters. The rule demands migrating *one* node at a time. For all node $i \in C_i$ migrated to $C_{j,j\neq i}$ forms a set *X*. Due to non-traversability, a feasible subset Y Ô X is obtained. In this mechanism, at least one equilibrium is achieved from the subset *Y*. The only criteria that should be followed is that the migrated node should not disintegrate its own cluster. Therefore, the migration is only possible for the boundary nodes ($b \in C_i$ and $\sum b = BB$ where *BB* is the number of boundary nodes *b* in cluster C_i), that are nodes connected to tie-lines. Although, it is possible to move more than one node but that will exhibit a substantial change in *f*. Also, the clusters or zones will lose its property of akin LMP on the basis in which they have been clustered. A flow index is explained next that will decide on the dominant strategy.

3.2.1 Cluster Power Flow Index (CPFI)

Based on the power systems physical properties, the concept of change in the real power flow when a perturbation occurs on the system is appropriately modeled in CPFI. This index evaluates the sum of the change in the real power flow with a single small perturbation in the network. A nodal perturbation within a cluster is created, to be balanced by another node within the same cluster. This is mathematically expressed as follows.

$$A^{i,j} = \frac{\sum_{lm\in S} || P_{lm}^{0} | - | P_{lm}^{new} ||}{\sum_{lm\in S} |P_{lm}^{0}|} \quad ....(7)$$

$$\forall\, i,j \in C_k \text{ for } k = 1,..,N$$

$$B^{i,j} = \frac{\sum_{xy\in T} || P_{xy}^{0} | - | P_{xy}^{new} ||}{\sum_{xy\in T} |P_{xy}^{0}|} \quad ....(8)$$

$$\forall\, i,j \in C_k \text{ for } k = 1,..,N$$

$$CPFI\% = \frac{\sum_{\forall i,j\in C} A^{i,j}}{\sum_{\forall i,j\in C} (A^{i,j} + B^{i,j})} \quad 4....(9)$$

The change in intra-cluster line power flows is recorded in equation (7) and that of lines outside cluster is stored in equation (8). It is easy to follow that, the clustering is said to be appropriate if $A^{i,j}$ is greater than $B^{i,j}$ in predominant cases. A consolidated effort of *f*, CPFI and silhouette analysis (SA) decide the best possible cluster formation for a pre-defined *N*. Moreover, based on above analysis, a judicious recommendation can be made on the suitable *N** that should be established to endure the perturbations. The dominant strategy, *Z*, is achieved based on equation (10). Flowchart of the above discussed process is given in Figure 1.

$$Z = \max(f \times CPFI \times SA) \;\; \forall \;\; Y \quad ....(10)$$

TABLE 1									
FIRST STEP FOR IEEE 30 BUS SYSTEM. CCI=1 ∀ N.									
N	**f**	**ECI**	**BCCI**	**CSI**	**CPFI**			**SA**	**Z**
					A	**B**	**CPFI%**		
3	0.8153	0.8226	0.9978	0.9932	272	4	98.55	0.3559	0.2860
4	0.8730	0.8836	0.9963	0.9917	196	4	98	0.2763	0.2364
5	0.9043	0.9099	0.9959	0.9979	150	2	98.68	0.0670	0.0598
6	0.9176	0.9245	0.9956	0.9969	122	0	100	-0.0125	-0.0115
7	0.9239	0.9302	0.9953	0.9979	100	0	100	-0.1741	-0.1608
8	0.9343	0.9416	0.9952	0.9969	84	0	100	-0.2374	-0.2218
9	0.9382	0.9492	0.9952	0.9932	72	0	100	-0.2157	-0.2024
10	0.9311	0.9666	0.9951	0.9678	64	0	100	-0.2109	-0.1964

4.0 RESULTS AND DISCUSSION

This section discusses the results of proposed method for network segmentation. The results have been obtained on IEEE-30 bus system [21] and modified Indian power network [22]. In our case, $\alpha, \beta, \gamma, \delta$ in equation (5) is assumed as *one*. The algorithm is implemented in MATLAB™ with the help of MATPOWER™ package [23].

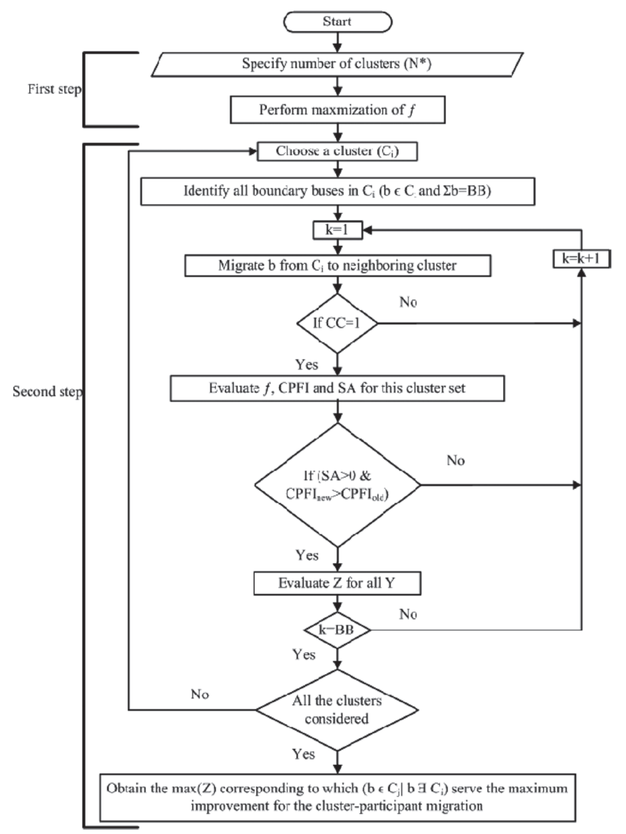

FIG. 1 FLOWCHART FOR TWO STEP NETWORK SEGMENTATION

4.1 IEEE-30 bus system

Results obtained for the first step are shown in Table 1. It can be observed that for *N* having $Z < 0$ can be rejected. Also, *N* having *Z* close to *zero* can be rejected due to blind zone demarcation. Thus, optimal number of clusters for this system are *three* or *four*. For *N=3*, the following buses form the cluster: {1-4, 12-14, 16}, {5-11, 17, 21, 22, 28}, {15, 18-20, 23-27, 29, 30} and for *N=4*, cluster consists of {1-4, 12-14}, {5-11, 16, 17}, {15, 18-24}, {25-30} buses.

For the second step of network segmentation, each boundary node is shifted to the neighboring cluster one-by-one. Performing zonal participant migration, it has been found that migration of bus 16 from cluster C_2 to cluster C_2 has a maximum improvement on *Z*, for *N=3*, as shown in the Table 2. Similarly, for *N=4*, migration of bus 28 from cluster C_4 to cluster C_2 shows the maximum improvement in *Z*. It is left with the policy maker to decide the optimal number of clusters, either *three* or *four*. From the Table 2, the most convincing optimal number of cluster is *three* as it suggests best performance in terms of CPFI%, and is shown in Figure 2.

TABLE 2

SECOND STEP FOR IEEE 30 BUS SYSTEM

N	3		4	
Step	**1st**	**2nd**	**1st**	**2nd**
f	0.8153	0.7933	0.8730	0.8445
ECI	0.8226	0.8241	0.8836	0.8949
BCCI	0.9979	0.9980	0.9963	0.9966
CSI	0.9932	0.9647	0.9917	0.9469
SA	0.3559	0.4124	0.2763	0.3646
A	272	281	196	204
B	4	3	4	4
CPFI%	98.55	98.94	98.00	98.08
Z	0.2860	0.3237	0.2364	0.3020

4.2 Modified Indian Power Network (MIPN)

Aggregated model of modified Indian power network consists of *193* buses having *52* generators (*23* coal, *6* gas, *5* hydro, *2* nuclear and *16* oil power stations), *452* branches, *41* shunts and *47* transformers with a total load of *21521.8 MW*. Results obtained for the first step are shown in Table 3. On the basis of N having $Z < 0$ (i.e. N=*8*, *9* and *10*) can be rejected. Moreover, for N having Z close to *zero* is appearing in the blind zone that suggests one can reject these clusters as well. Hence, N=*3*, *4* and *5* becomes optimal choice of clusters for the grid. For cluster C_i where $i = 1,...,3$, consists of {74, 64, 55} number of buses, for cluster C_i where $i = 1,...,4$ consists of {36, 43, 55, 59} number of buses and for cluster C_i where $i = 1,...,5$ consists of {35, 43, 50, 39, 26} number of buses, in each cluster.

For the second step are shown in Table 4 of network segmentation for the grid, after implementing zonal participant migration, it has been found that moving bus 162 from cluster C_2 to cluster C_1 improves Z to its maximum, for N=*3*, as shown in the Table 4. For N=*4*, transferring of bus 118 from cluster C_4 to cluster C_3 shows the maximum improvement in Z. For N=*5*, moving bus 161 from cluster C_5 to cluster C_3 shows the maximum improvement in Z. The possible optimal number of clusters for the grid are *three*, *four* and *five*. From the Table 4, the most convincing optimal number of cluster is *five* as it suggests best performance in terms of CPFI%, and is shown in Figure 3.

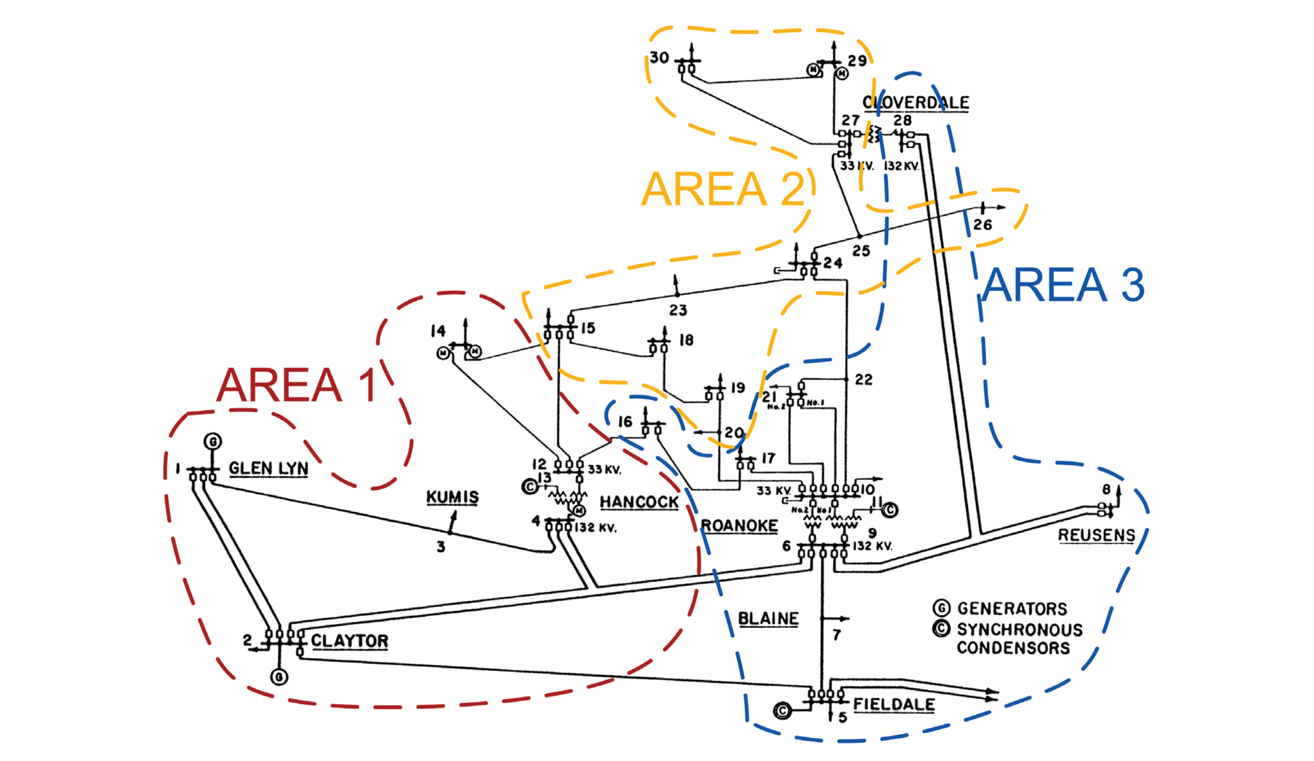

FIG. 2 IEEE 30 BUS SYSTEM - 3 CLUSTERS

TABLE 3									
FIRST STEP FOR MIPN. CCI=1 ∀ N.									
N	**f**	**ECI**	**BCCI**	**CSI**	**CPFI**			**SA**	**Z**
					A	**B**	**CPFI%**		
3	0.7860	0.8479	0.9284	0.9985	8763	3641	70.65	0.4844	0.2690
4	0.8028	0.8997	0.9005	0.9908	7090	2368	74.96	0.2747	0.1653
5	0.8019	0.9347	0.8691	0.9872	6496	1082	85.72	0.3725	0.2561
6	0.7703	0.9362	0.8432	0.9757	5451	937	85.33	0.0449	0.0296
7	0.7463	0.9508	0.8209	0.9563	4954	610	89.04	0.1144	0.0760
8	0.7063	0.9482	0.7666	0.9717	4312	454	90.47	-0.0431	-0.0275
9	0.6898	0.9624	0.7275	0.9852	3942	196	95.26	-0.0284	-0.0187
10	0.6586	0.9656	0.6967	0.9789	3534	206	94.49	-0.0669	-0.0416

TABLE 4						
SECOND STEP FOR MIPN						
N	**3**		**4**		**5**	
Step	**1st**	**2nd**	**1st**	**2nd**	**1st**	**2nd**
f	0.7860	0.7844	0.8028	0.8027	0.8020	0.7982
ECI	0.8480	0.8481	0.8997	0.9012	0.9347	0.9356
BCCI	0.9284	0.9271	0.9005	0.8995	0.8691	0.8679
CSI	0.9985	0.9976	0.9908	0.9903	0.9872	0.9831
SA	0.4844	0.4895	0.2747	0.2882	0.3725	0.3810
A	8763	8949	7090	7190	6496	6584
B	3641	3503	2368	2278	1082	1044
CPFI%	70.65	71.87	74.96	75.94	85.72	86.31
Z	0.2690	0.2759	0.1653	0.1757	0.2561	0.2625

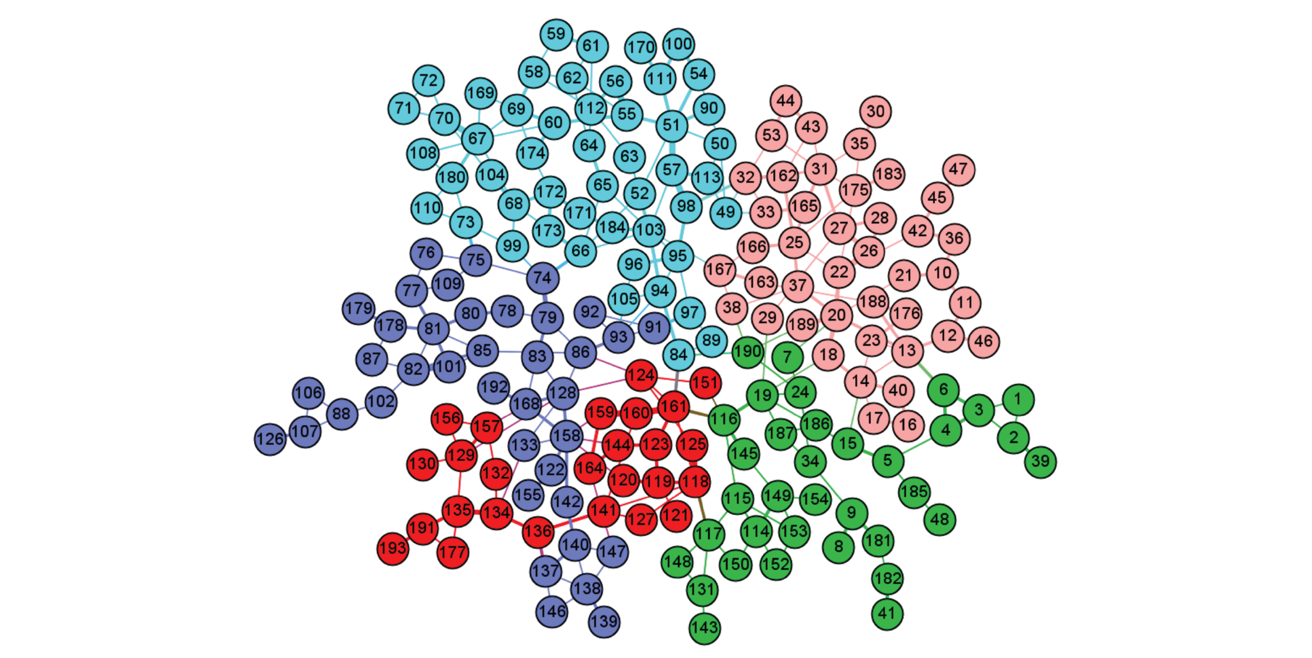

FIG. 3 MIPN - 5 CLUSTERS

5.0 CONCLUSION

A multi-step network segmentation process has been proposed in this paper. The results of first step involving optimization leave some room for fine readjustment in terms of accommodation of certain set of buses to a better fit cluster. The same has been exploited to devise the second step that involves bus migration to other clusters. It is shown that the performance index improves under certain cases of bus migration. Hence, the results at the end of second step provide appropriate zone formation from the congestion perspective. These zones further get converted into pre-defined bidding areas to be used in power exchanges. The results obtained on IEEE 30 bus system and modified Indian power network establish the usefulness of the proposal.

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