Decentralized And Simultaneous Generation and Transmission Expansion Planning Through Cooperative Game Theory

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Abstract: In the new paradigm, electric power system development should provide a negotiation space mechanism between all players with the objective function to maximize payoff distributed to each player in the system. Uncertainty risk and operate effectively and efficiently become a high consideration for all players in the decision making processes to select an investment and power system operation. This paper deals with simultaneous and desentralized with multiple objectives scenario within a global framework. The planning mechanism is prepared on the basis of cooperative game theory. Its coperative framework will encouraged an independently, distributed decision making in the competitive structure environtment. Main contributions of this paper are: a general model for power system planning in the form of cooperative game theory, and its time and spatial decomposition. This method will be implemented in Garver test system.

Index Terms: power system planning, game theory, Shapley bilateral, coalition formation, static security

1. Introduction

Decentralized policy of natural resources management, existing disparity of electric demand in sector classification and in regional level, also the needs for unbundling vertically integrated electric power business stimulate and modify significantly the process and mechanism in power system planning and development. Traditionally, electric power system planning was conducted as a centralized planning with the objective function to minimize investment and operation cost in a framework of welfare maximization for an established reliability services. In line with the restructuring of power industry, some research works have appeared on power system planning on the basis of competitive structure. Due to the the complexity of the problem itself, and some ambiguities in the policies regarding relationship between long-term planning horizon and day by day operations of deregulated power system, the models developed so far are not yet able to compatible to the needs of planners and policy-makers.

In the new paradigm, electric power system development should provide a negotiation space mechanism between all players with the objective function to maximize payoff distributed to each player in the system. Uncertainty risk and operate effectively and efficiently become a high consideration for all players, including independent power producers, transmission owners, independent system operators and consumers in the decision making to select an investment and power system operation. Consequently, power system planning deals with a decentralized planning with multiple objectives scenario within a global framework, and its planning mechanism should be able to evolve adaptively on a number of planning horizons.

There have been a few research works on simultaneous generation and transmission expansion planning. Initial work conducted by incorporating the costs of generation and transmission facilities in a single objective formulation, that minimize total investment cost. A transportation models has been used to represent transmission existing network and its candidate expansion planning.

Solution approach has been based on combination of Benders decomposition, maximum flow algorithms and linear programming used to power flow network [1,2].

Some research works in this field appear significantly, especially in application of game theory and reinforced learning. Vishnu Nanduri et all [11] propose a generation expansion planning using two-tier game theory with transmission network constraint in multi years planning. It also apply reinforced learning to solve matrix game of generation and transmission network development. Jianhui Wang [12] works also using a combination of coevolutionary computation with 2-level optimization for generation expansion planning. In other side Lina P Garces proposes a bilevel programming for transmission network expansion within uncertainties of power system market [7]. M Sadegh et all [8] works on simultaneous generation and transmission expansion conducted in a centralized planning using mixed integer non linear programming that includes variation of fuel cost based on type and locational geography. Jae Hyung Roh and M Shahidehpour propose a model for power system planning coordination of energy market and its transmission with a capacity cost of generation and transmission facilities [13]. Capacity payment is designed to enhance market investment, and also able to reflect locational value for addition of resources. This interaction is provided as iteratif mechanism within GenCo, TransCo and ISO and simulate it using Monte Carlo.

This paper deals with a concept and mechanism of planning processes in which is able to accommodate negotiation process and to compose a strategy of all players, hence a Pareto-Optimal outcome solution will be achieved in electric power system. The planning mechanism is prepared on the basis of cooperative game theory. Its coperative framework will encouraged an independently, distributed decision making in the competitive structure environtment.

2. Problem Formulation

In the competitive structure, such as in Figure 1, regarding the increasing load demand in each area A, B and C, there are some choice independently in power system planning as a respons to meet the electric demand, that include : (i) running an expansion planning in each region to solve each problems, (ii) enhancement a tie line and import energy from another area, (iii) built a new plan and enhancement a tie line and sold its excess energy to another area.

Concerning the problems, a new approach is prepared to solve this problem using cooperative game mechanism. It provides a capability to propose an oportunity for all players to negotiate and stimulate interaction between them to make a coalition formation on the basis of individual competitive preferences.

For the system above, the players interact in the system include NewLoad, GenCo, TransCo as an owner of transmission network in each ara and tie line. It is assumed that all players are rational, and are always willing to maximize its profit in the planning.

In the simultaneous expansion generation and transmission planning, all players commited to (i) meet the load requirement within static security and economic constraints; (ii) all of cost for expansion planning will be provided together and all of benefit form that will be distributed based on marginal effort conducted by each player; (iii) shapley value mechanism will be used to allocated its benefit.

A. Basic Formulation

Consider a general N-persons cooperative game in which a player–i will maximize/minimize its objective function :

$$\int_{t_0}^{T} g^i[s, x(s), u_1(s), u_2(s), ..., u_n(s)]ds + q^i(x(T)),$$

$$for\ i \in N = \{1, 2, ..., n\} \tag{1}$$

With the state dynamics in the form :

$$\dot{x}(s) = f[s, x(s), u_1(s), u_2(s), u_3(s)......, u_n(s)],$$
$$x(t_0) = x_0 \qquad (2)$$

$x(s) \in X$ states as variable state of the game, and u_i ■ v^i apply as a control part of player-i, for each $i \in N$.

In this case the players agree to cooperate and allocate cooperative payoff to fulfil the optimality principle of cooperative scheme. The solution of optimality principle will run along the cooperative state trajectory path $\{x_s^*\}_{s=t_0}^T$, that will be found rationally each player such a number of strategic sets to obtain Pareto optimal solution, and each allocation should meet a individual rationality.
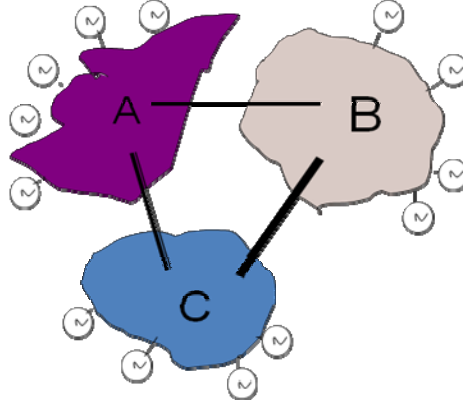

Figure. 1. Interarea electricity structure connedted by tie line, each area has an different generation, transmission and load

To fulfil group rationality of cooperative mechanism, the players have to maximize the sum of their payoffs subject to state dynamics equation above:

$$\sum_{j=1}^N \{\int_{t_0}^T g^j[s, x(s), u_1(s), u_2(s), u_3(s), ..., u_n(s)]ds + q^j(x(T))\} \qquad (3)$$

With Pontryagins Maximum Principle, there are sets of optimal control u*(s)=[u*(s), u*(s), u*(s), u*(s)... ...] Subisituting this set of optimal control into (3) yields the optimal trajectory $\{x_s^*\}_{s=t_0}^T$, where

$$x^*(t) = x_0 + \int_{t_0}^t f[s, x(s)u^*(s)]ds,$$
$$for \ t \in [t_0, T] \qquad (4)$$

The objective function for optimal trajectory condition is :

$$\sum_{j=1}^n \{\int_{t_0}^T g^j[s, x^*(s), u^*(s)]ds + q^j(x^*(T))\} \qquad (5)$$

where $v(N; x_0, T - t_0)$.

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B. Cooperative Game Theory

The term of characteristic function was noted by *v*. The characteristic function is defined as: for every subset S from N, the characteristic function *v* of a game gives the biggest value *v(S)* obtained by the members of *S* if they work together and form a coalition, without any assistance from the other players outside *S*.

The boundary of this definition is the game value toward empty coalition is zero so that *v (Ø)* = 0. Shapley value is a measure of average contribution given by one player to the game. This value is related to the marginal value in economic study. For example, a coalitional game with definite player set *N= {1, 2, 3...n}* with the characteristic function *v* of 2^N possible coalition set. *N* is the number of player in *S* coalition. *v(S)* represents the total payoff that can be obtained by S coalition with player i involved in coalition and *v(S-{i})* is payoff obtained without the player *i*. Shapley value is represented by *φ* operator. *$φ_i$* is the payoff of player *i* in the game. The marginal contribution of player i is *v(S) - v(S-{i})*. The formula of Shapley value is:

$$\Phi^v(x_0, T - t_0) = \{\Phi_i^v(x_0, T - t_0), i = 1, \ldots, n\}$$
$$\Phi_i^v(x_0, T - t_0) =$$
$$\sum_{S \subset N, i \subset S} \frac{(n-1)!(s-1)!}{n!}[v(S; x_0, T - t_0) - v(S \setminus i; x_0, T - t_0)];$$
$$i = 1, \ldots, n$$

(6)

To avoid the combination complexity in Shapley value calculation, Ketchpel introduced Bilateral Shapley Value (BSV). This BSV approach has been used for decentralization and bilateral negotiation process among rational players.

If $C \subseteq P(A)$ is a coalition structure from set of agent A = *{$a_1, \ldots, a_m$}*, where $C = C_i \cup C_j \subseteq A$ and $C_i \cap C_j = Ø$. Then *C* is a coalition (bilateral) of disjoint coalition (n-agents) C_i and C_j *(n ≥ 0*. The Bilateral Shapley Value for coalition C_i in bilateral coalition *C* is defined as:

$$\Phi_C(c_i) = \frac{1}{2}v(c_i) + \frac{1}{2}\{v(c) - v(c_j)\}$$

(7)

C_i and C_j coalition are called as the composer of coalition *C*, C_i as well as C_j will form coalition *C* if:

$$v(C_i) \le \varphi_C(C_i) \text{ and } v(C_j) \le \phi_C(C_j)$$

(8)

3. Propose Model For Development Planning

A. Improving Load Point Reliability Index

A Garver test system as Figure 2 will be used as a model to show the application of cooperative game for power system planning. It has 2 generating plants 1x150 MW and 1x 120 MW, 5 bus and 6 lines, with total load is about 190 MW.

Based on the existing condition, load at each bus is peak load, with load fator about 1. The composite reliability at each load is represented as value of EENS (Expected Energy Not Served). Total EENS at Garver system is about 16,46 GWh per year, and is distributed for each bus as load point index per year, with a composition as : EENS at bus-1, bus-2, bus-3, bus-4 and bus-5 are about 0,28 GWh, 1,9 GWh, 0 GWh, 10,7 GWh, and 1,14 GWh respectively.

Improving of Garver model will be conducted using a heuristic planning to obtain a better reliability with load point index as EENS = 0 at each bus, for normal and N-1 contingency operation.

There are some alternative solutions to improve Garver system, include : (i) increase reserve capacity at bus-3, (ii) enhancement transmission for each branches; and do for (i) and (ii) simultaneously. Algorithm for choice the configuration alternatives shown as following below:

Algorithm 1

Step 1 : (**Initialitation**) *data of existing generation and transmission and load.*
Step 2 : *Calculate EENS existing system based on composite reliability at load point*
Step 3 : *(**Loop 1**) If EENS = 0 , then finish and run to step 7*
3.1 Add capacity of generation at certain bus
3.2 Running optimal ower flow
*3.2.1 (**Loop 2**) If feasible optimal power flow, **then** finish to step 3*
  (i) Add line branch i
  (ii) Running optimal power flow

*3.2.2 (**Loop 3**) If feasible optimal power flow, **then** finish to step 3*
  (i) Running load shedding at certain bus
  (ii) Running optimal power flow
  (iii) Back to step 3.2.2 loop 3
Step 4 : *Running N-1 contingency analysis*
Step 5 :
  Calculate EENS for configuration k-th; calculate annualized investment for k-th; calculate the ratio of delta EENS to annualized generation and tranmission investment.
Step 6 :
  Sorting all configuration 1-st to k-th based on ratio above, and choose the configuration
Step 7 : *Finish and stop.*

Planned configuration will be used on the basis of highest ratio of delta EENS to annualized investment needed. Based on algorithm-1, coalition between of existing network configuration with exteded generator 80 MW at bus 3 will solve the requirement of reserve power for N-1 contingency, for example generator 150 MW failed to supply the system.

Economic dispatch mechanism is based on optimal power flow analysis and if the result is not feasible (over load in line from bus-2 to bus-3 and under voltage at bus-4), than load shedding mechanism at bus-4 will be done about 7 MW. EENS is calculated for each possible configuration.

Calculation result is shown in table 1 and based on this result configuration 8-th will selected in which coalition between (i) existing system Garver, (ii) new additional generation plant abot 80 MW, and (iii) enhancement of transmission line between bus-2 to bus-3, with ratio about 3.126 KWh/$ investment per year. The configuration result is shown as figure 3.

Investment cost of configuration 8-th becomes a characteristic function of existing system Garver 5 bus. It effects to payoff distributed if the existing system cooperate with another players. Payoff obtained by exsiting Garver will face as a decreasing of investment cost because some of investment is provided by another players, such as New GenCo or TransCo and New Load that will collaborate to the system.
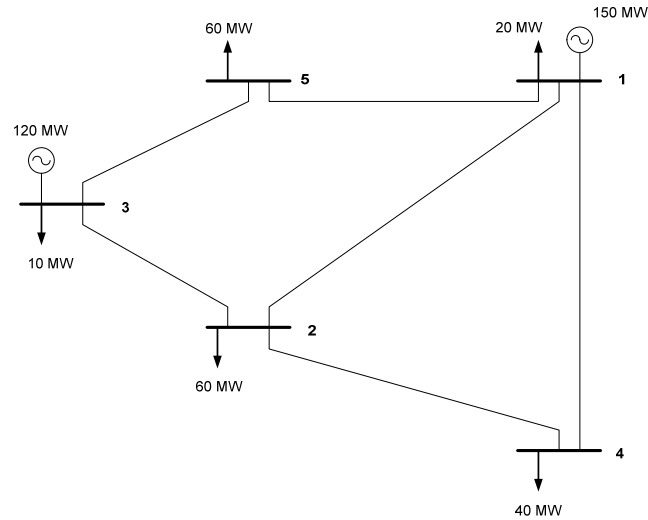
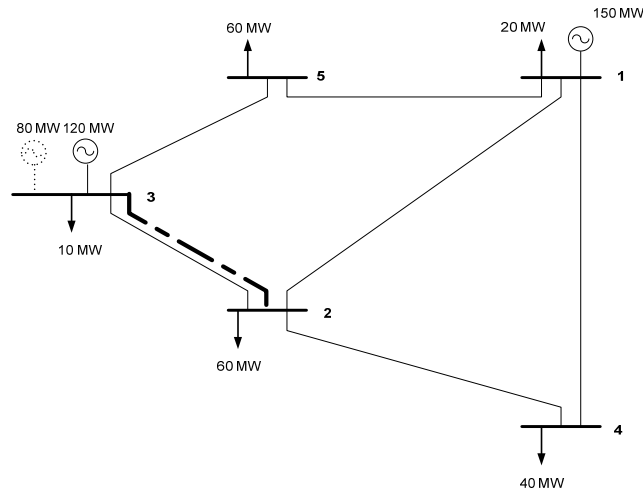Figure. 2. The existing models of generation and transmission lines of Garver system.

Figure 3 Configuration 8-th to improve reliability at load point, coalition between existing system Gaver, New Generating Plant 80 MW, and enhancement tranmission line from bus2 to bus 3.

4. Test Case

As explained by cooperative game theory principle, players always try to maximize their profit. In this planning process, payoff acquired by creating a coalition is a reduced investment cost. This is because, by creating a coalition, player can create an agreement to divide payoff according to marginal effort of each player. In this condition, coalition will always happen if each player gets payoff at least the same as payoff acquired before coalition. Previous assessment of Garver system can be developed by taking into load expansion for every bus. Thus, there are eight players in the simultaneous planning process of generation system and transmission network:

Player I:

Existing system, which includes 5 buses, 2 existing generator in bus 1 and bus 3, 6 transmissions that connect buses, and existing load.

Player II:

Generator Company, called GenCo, which will build a new generator in bus 3.

Player III:

Transmission Company, called TransCo, which will build transmission network for existing buses.

Player IV, V, VI, VII, and VIII:

Consumers that require electricity in bus 1, bus 2, bus 3, bus 4, and bus 5. The requirement of the company is known previously.

Planning Principle:

The principles in this planning process should (i) meet the requirement for both existing and new loads (ii) satisfy the need of static security criterion and condition of ENNS = 0 in N-1 contingency and by (iii) maximize payoff acquired by each player.

A. Individual Characteristic Function

The players will have their own characteristic function and will create coalition with other player, to achieve higher payoff. In this planning, all players have significant needs to existing system due its existing infrastructure. With the existence of load in bus 1 through bus 5, existing system will be subjected to declining rate of composite reliability in every bus and increasing EENS. Coalition between existing system and GenCo increase system reliability to fulfill load demand and to decrease EENS that occurs.

B. Coalition Development

Coalition between existing system and TransCo will also increase system reliability to meet load demand and to decrease EENS that occurs. Coalition between every player will increase system reliability to fulfill load demand, to decrease EENS and to increase payoff for every player.

This payoff is higher than payoff for fulfilling needs marginally. As such, every player will have significant needs to existing system because existing system has fundamental network configuration. This network configuration is a way for other players to give their benefit so that the players will have increased profit.

In the first case, GenCo will be able to supply power to load through transmission line in the existing network. For GenCo, utilizing existing network is more profitable than investing in building new transmission network to the load. Principally, GenCo may develop new transmission rather than using existing transmission line to load center if it is more profitable in the end. Coalition between GenCo and existing system will increase system's reliability because GenCo can increase reserved power to load center when contingency occurs, especially in case of generation outage from the system.

In conclusion, the coalition gives benefit to existing system, load, and GenCo according to marginal effort of every player. This will cause a coalition payoff distribution for the players. GenCo obtains profit in the form of revenue that is obtained from system revenue because system can reduce investment cost to improve system's reliability. Investment cost can be reduced because system does not need to build its own generator. Furthermore, operationally, GenCo will also obtain profit from electricity market. In line with rationality principle, GenCo should obtain higher payoff than its characteristic function.

In the second case, TransCo cannot operate on its own transmission lines because there is no profit obtained in relation to increased reliability. On the other hand, if TransCo enters a coalition with existing system, TransCo will give benefit for system because system rreliability will be increased. The system reliability is increased because of new line developed by TransCo. TransCo can ensure power supply to load center both in normal operational condition and in contingency operational condition. Thus, security criterion is fulfilled by the system.

In conclusion, in relation to marginal effort of TransCo, TransCo will obtain its payoff share from reduced investment cost for developing new transmission line by existing system or existing coalition with GenCo. This is because TransCo provides the new transmission line. Operationally, TransCo will obtain rent fee of the line.

In the third case, the player is load. Coalition between this load and existing system or existing coalition with GenCo and TransCo will reduce investment that should be provided by the load. By entering a coalition with the system, the load will obtain profit because the load does not have to invest in building its own generator.

Table 1
Configuration Alternatives and Its Coalition for Improving Reliability

Confi guration	Coalition			EENS						Invest.	ENS Cost	Ratio
	Existing	GenCo at Bus 3 (MW)	Line	Bus-1 (MWh)	Bus-2 (MWh)	Bus-3 (MWh)	Bus-4 (MWh)	Bus-5 (MWh)	Total (MWh)	(Mill. $)	(Mill.$)	(Kwh/$)
Existing	Ok	-	-	2.786,5	1.899,9	-	10.639,2	1.139,9	16.465,5	-	1,140	
2	Ok	80	-	-	-	-	1.123,0	-	1.123,0	4,835	1,123	2,575
3	Ok	-	Line 2-3	2.783,3	1.897,7	-	10627,1	1012,1	16.320,2	0,115	16,320	0,009
4	Ok	-	Line 2-4	2.780,1	1.895,5	-	10.615,0	1.137,3	16.427,9	0,231	16,428	0,002
5	Ok	-	Line 1-2	2.783,3	1.897,7	-	10.627,1	1.012,1	16.320,2	0,115	16,320	0,009
6	Ok	-	Line 3-5	2.780,1	1.769,2	-	10.615,0	1.137,3	16.301,6	0,230	16,302	0,010
7	Ok	-	Line 1-5	2.783,3	1.771,2	-	10.627,1	1.138,6	16.320,2	0,115	16,320	0,009
8	*Ok*	*80*	*Line 2-3*	*-*	*-*	*-*	*-*	*-*	*-*	*5,268*	*-*	*3,126*
9	Ok	80	Line 2-4	-	-	-	746,9	-	746,9	5,264	0,747	2,615
10	Ok	80	Line 1-2	-	-	-	1.120,4	-	1.120,4	5,065	1,120	2,481
11	Ok	80	Line 1-4	-	-	-	497,4	-	497,4	5,565	0,497	2,634
12	Ok	80	Line 3-5	-	-	-	-	-	-	5,321	-	3,094
13	Ok	80	Line 1-5	-	-	-	747,8	-	747,8	5,165	0,748	2,658

Table 2
Individual Characteristic Function of Each Player

| Pemain	Investment needed *)		Investment (Mill. US$)		Characteristic
	Power Plant at Bus-3	Line	Power Plant	Line	Function in Mill US$
Exsisting	PLTU 80 MW	Saluran 2-3	5,153	0,115	-5,268
GenCo	-	-	-	-	-
TransCo	-	-	-	-	-
Load at Bus-1 10 MW	Diesel 2x 10 MW	-	0,795	-	-0,795
Load at Bus-2 40 MW	Diesel 2x 40 MW	-	3,179	-	-3,179
Load at Bus-3 5 MW	Diesel 2x 5 MW	-	0,379	-	-0,379
Load at Bus-4 10 MW	Diesel 2x 25 MW	-	1,987	-	-1,987
Load at Bus-5 10 MW	Diesel 2x 60 MW	-	4,769	-	-4,769
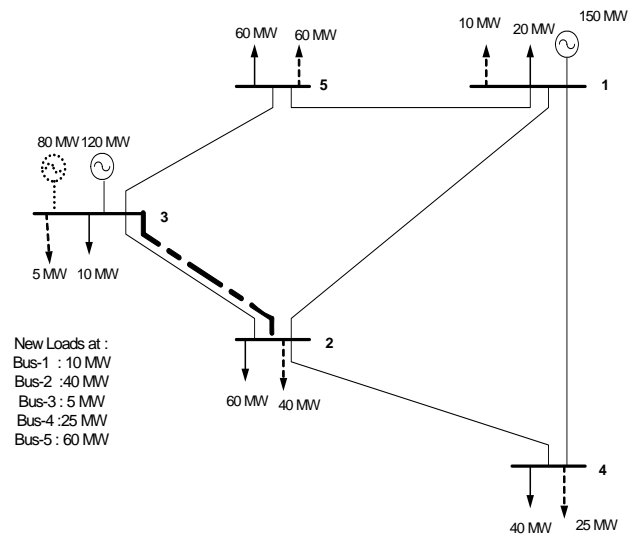
Figure 4 New configuration planned that consist of existing power system, New Generator 80 MW at bus-3, and enhancement new lines from bus-2 to bus-3, and estimated additional load at each bus.

Table 3
Coalition Characteristic Function of Each Coalition

Coalition	Players and Coalition	Coalition Investment	Charactristic Functions in Mill. US$
1	Eks	Gen 1 x 80 MW, 1 x line-1	-5,269
2	GenCo	No Investment needed in its coalition	0
3	TransCo	No Investment needed in its coalition	0
4	NL1	Diesel Gen 2 x 10 MW	-0,795
5	NL2	Diesel Gen 2 x 40 MW	-3,179
6	NL3	Diesel Gen 2 x 5 MW	-0,379
7	NL4	Diesel Gen 2 x 25 MW	-1,987
8	NL5	Diesel Gen 2 x 60 MW	-4,769
9	Eks-GenCo	1 x line-1	-0,115
10	Eks-TransCo	Gen 1 x 80 MW, 1 x line-1	-5,153
11	Eks-NL1	Gen 1 x 90 MW, 1 x line-1	-6,001
12	Eks-NL2	Gen 1 x 120 MW, 1 x line-1	-8,116
13	Eks-NL3	Gen 1 x 85 MW, 1 x line-1	-5,605
14	Eks-NL4	Gen 1 x 105 MW, 1 x line-1, 1 x line-2	-7,326
15	Eks-NL5	Gen 140 MW, 1 x line-1, 1 x line-5	-9,482
16	Eks-GenCo-TransCo	No Investment needed in its coalition	0
17	Eks-GenCo-NL1	1 x line-1	-0,115
18	Eks-GenCo-NL2	1 x line-1	-0,115
19	Eks-GenCo-NL3	1 x line-1	-0,115
20	Eks-GenCo-NL4	1 x line-1, 1xline-2	-0,346
21	Eks-GenCo-NL5	1 x line-1, 1xline-5	-0,231
22	Eks-GenCo-TransCo-NL5	No Investment needed in its coalition	0
23	Eks-GenCo-NL1-NL5	1 x line-1, 1xline-5	-0,231
24	Eks-GenCo-NL2-NL5	1 x line-1, 1xline-5	-0,231
25	Eks-GenCo-NL3-NL5	1 x line-1, 1xline-5	-0,231
26	Eks-GenCo-NL4-NL5	1 x line-1, 1xline-5, 1 x line-2	-0,461
27	Eks-GenCo-TransCo-NL2-NL5	No Investment needed in its coalition	0
28	Eks-GenCo-NL1-NL2-NL5	1 x line-1, 1xline-5	-0,231
29	Eks-GenCo-NL2-NL3-NL5	1 x line-1, 1xline-5	-0,231
30	Eks-GenCo-NL2-NL4-NL5	1 x line-1, 1xline-5, 1 x line-2	-0,461
31	Eks-GenCo-NL2-NL4-NL5-TransCo	No Investment needed in its coalition	0
32	Eks-Genco-NL1,NL2-NL4-NL5	1 x line-1, 1xline-5, 1 x line-2	-0,461
33	Eks-Genco-NL1,NL2-NL3-NL4-NL5	1 x line-1, 1xline-5, 1 x line-2	-0,461
34	Eks-Genco-NL1,NL2-NL3-NL4-NL5-TransCo	Tak ada investasi di koalisi	0

Increasing load at each bus will decrease a reliability level, and it needs a network reconfiguration to obtain its reliability previously. For this case, to obtain EENS = 0 at N-1 contingency, heuristically it needs an additional capacity at bus 3 to supply a reserve power, and expanding the existing network in all branches.

Algorithm 2

Step 1 : (**Initialitation**)
(i)   *Existing data for generating plant, transmission network and existing load, an estimated incremental load for each bus per year,*
(ii)   *Establish operation criteria include static security, meet demand and EENS=0 at N-1 contingency.*

Step 2 :
(i)   *Establish the first year of planning k=1*
(ii)   *Establish heuristically alternatives of generating plant location and new transmission network*
(iii) *Calculate individual characteristic function of all players: Existing, GenCo, TransCo and New Load. The value of individual characteristic function are calculated on the basis of investment cost in power plant or transmission lines and ENS Cost.*

Step 3 :
   Arrange coalition between players i-th , i=1 to N. For this purpose, consider the requirements of coalition structure that includes power and energy balance, the connection between generating plant, transmission lines and load.
   For each coalition i-th, running an optimal power flow
         ***If** optimal power flow is feasible, **then** construct a coalition i-th*
            Add new line in brach i-th,
            Add generating capacity at certain bus
            Running optimal power flow
            Calculae also EENS of the coalition i-th

Step 4 :
   Calculate the characteristic function of coalition i-th
   Calculate Shapley Bilateral Value for its coalition
   Choose the coalition i-th

Step 5 :
   Calculate investment allocation for ecah player
   Calculate payoff for each player
   Compare payoff each players with individual investment of each player

Step 6 : *Finish, set its configuration as planning result.*

For this case, payoff obtained by GenCo is cost allocation from grand coalition, includes revenue from energy sold minus fuel cost and operation and maintenance cost. Payoff achieved by TransCo is cost allocation from grand coalition plus payment form rent cost of transmission line.

C. Planning result

   Bilateral Shapley Value calculation is conducted to see the maximum payoff obtained by existing system regarding the coalition of 2 players, 3 players, 4 players, 5 players, 6 players, 7 players, and grand coalition that it consists of existing system and other players.

   For example, BSV calculation is provided for coalition 11 in table 3, between existing system and New Load at bus-1 NL1. Characteristic function of coalition of 2 players (existing system and NL1) is about 6,001 Mill.US$, in the form of investment planning for generating plant of 90 MW, and new installation of transmission lines from bus-2 to bus-3.

Individual Characteristic function of existing system is about 5,269 Mill. US$ in the form of investment needed to increase reliability level up to EENS=0 at N-1 contingency condition. In other side, individual characteristic function of NL1 is about 0,795 Mill.US$. Based on data explained above, it is able to calculate,

1. BSV for existing players = 0.5x -5.269 + 0.5 x (-6.001 -(-0.795)) = -5.2375 Mill. US$
2. BSV for NL1 player = 0.5x -0.795 + 0.5 x (-6.001 -(-5.269)) = -0.7635 Mill. US$
3. From this calculation, it can be shown that existing system obtains a benefit about 0.0315 Mill.US$, that is a differences between the investment needed to increase reliability level to investment needed that should be paid to if it has a coalition with NL1.
4. Therefore, the player NL1 has a benefit about 0.0315 Mill.US$, in which it is a differences between individual investment of NL1 to investment should be paid to system in its coalition.

On the basis of NSB calculation for 2 players coalition as in table 4, then existing system has a control authority, and is able to choose GenCo as a first coalition, due to maximize benefit obtained by existing player. This 2 players coalition generates a benefit of 2,577 Mill. US$ for each player.

Table 4
Pay off Distribution for 2 Players Coalition

Coalition	NSB		Benefit	
	Exist	GenCo	Exists	GenCo
Existing -GenCo	-2,692	2,577	2,577	2,577
	Exist	TransCo	Exist	TransCo
Existing -TransCo	-5,211	0,058	0,058	0,058
	Exist	NL1	Exist	NL1
Existing -NL1	-5,2375	-0,7635	0,0315	0,0315
	Exist	NL2	Exist	NL2
Existing-NL2	-5,103	-3,013	0,166	0,166
	Exist	NL3	Exist	NL3
Existing-NL3	-5,2475	-0,3575	0,0215	0,0215
	Exist	NL4	Exist	NL4
Existing-NL4	-5,304	-2,022	-0,035	-0,035
	Exist	NL5	Exist	NL5
Existing-NL5	-4,991	-4,491	0,278	0,278

Based on algorithm 2, it can be shown that the payoff distribution to each player for every coalition occurs as in table 5.

Table 5
Pay off Distribution For Each Coalition Step

	Eks	GenCo	TransCo	NL1	NL2	NL3	NL4	NL5	Investment In Mill,US$
Coalition of 1 player	-5,269	0,000	0,000	-0,795	-3,179	-0,379	-1,987	-4,769	-16,378
Coalition of 2 players	-2,692	2,577							-0,115
Coalition of 3 players	-1,529	3,740						-2,443	-0,231
Coalition of 4 players	-1,131	4,138			-1,590			-1,648	-0,231
Coalition of 5 players	-1,022	4,247			-1,150		-1,109	-1,428	-0,461
Coalition of 6 players	-0,997	4,272		-0,398	-1,051		-0,910	-1,378	-0,461
Coalition of 7 players	-0,991	4,278		-0,303	-1,027	-0,190	-0,862	-1,367	-0,461
Coalition of 8 players	-0,987	4,282	0,231	-0,245	-1,013	-0,074	-0,834	-1,359	0,000

The configuration result of each step coalition is shown as Figure 5
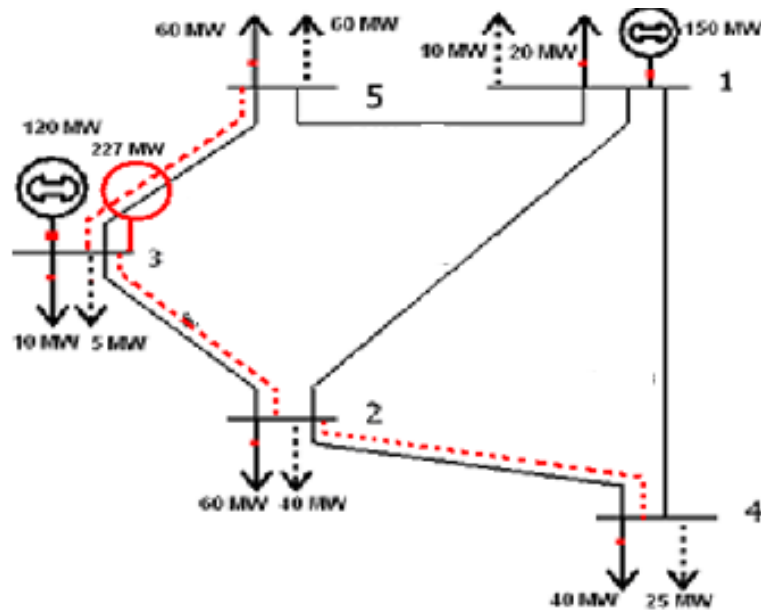

Figure 5 New configuration planned that consist of existing power system, New Generator 227 MW at bus-3, and enhancement new lines from bus-2 to bus-3, from bus-2 to bus-4, and line from bus 3 to bus 5.

5. Conclusion

Decentralized and simultaneous planning of electric power generation and transmission network that provides negotiation space for players in the process can be accomplished by using cooperative game theory. In this developed planning process, operational aspect, such as operational security criterion, is included in every process of coalition in its desired EENS value. In every process of coalition, players in the system can negotiate their commitment in determining characteristic function value. This characteristic function value is used to determine Shapley Bilateral value while also influencing the process of coalition between players. In conclusion,

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(a) Coalition in every process of cooperative game provides negotiation option between each player and option for a player to enter the coalition earlier than the other players.

(b) Player that enters the coalition earlier will have higher payoff than others that enter the coalition later.

(c) In the case of simultaneous planning of generation system and transmission network, with GenCo, TransCo, Existing Network and New Load as players, it can be shown that player with high capacity will have opportunity to enter coalition eralier than the other players.

(d) Negotiation process in this game mechanism can be accomplished by adjusting characteristic function value that is given in the early process of coalition.

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