40

INDONESIAN URBAN ELECTRIFICATION

A Case of 500 KV EHV Jamaly System

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Introduction

Indonesia is the world's fourth most populous nation, with 240 million people spread over a large archipelago of more than 922 permanently islands, which is a unique feature that has a significant impact on their electricity systems. The population within Indonesia is concentrated, with about 80% living on Java-Madura-Bali (known as Jamali) (IEA, 2008). At least, three out of the five biggest city in Indonesia reside in Jamali, namely Jakarta which is a Capital City of Indonesia, Surabaya and Bandung.

This situation brings Jamali into beeing a model of urban electrification in Indonesia which is organized as an integrated system and consisted of 4-regions, namely Region I: Banten and DKI Jakarta, Region II: West Java, Region III: Central Java and Yogyakarta and Region IV: East Java and Bali (RUPTL, 2010). For this purpose, PT. Perusahaan Listrik Negara (Persero) or PLN, the electricity sector coordinater and a 100 percent state-owned have built around 22.599 MW generating capacity. To transmit the energy, PT. PLN developed 2-interconnection systems, namely 500 KV Extra High Voltage (EHV) system as a back bone that reached 5,092 kmc and 150 KV system as a suporter that reached 15,501 kmc.

The high electricity demand reached an average 7% per year is not balanced compared to the growth in electricity supply. The GOI has limited capacity to mobilize the investment required to finance the required expansion of its electricity industry. The lack of investment in electricity generation capacity and network infrastructure is increasingly being felt through power restrictions, blackouts and power quality issues [ADB, 2010]. These have hindered the development of urban life.

In 2009, the GOI enacted Law Number 20 on Electricity which has increased the dynamic of electricity deregulation dan changed PT. PLN into no longer the authorized agency of electricity business. As GOI in generation sector encourages the private participation, the private generation stations are located at suitable locations by different companies (Independent Power Producers, IPP) and power is suplied to their bulk-costumers on bilateral contracts (Power Puschase Agreement, PPA) utilizing the existing transmission network of the PT. PLN's utility.

Restructuring the system is also taking place in all of the Jamali utility. The regions are already bundled in the form of generation but not in transmission and distribution companies. In this context it is important to asses the utilization of resources by PT. PLN's involved. In this paper a case study on generator contribution towards load and transmission flow which is an image of Indonesian urban electrification are ilustrated with an equivalent 9-bus system, a part of 500 KV Jamali grid, based on the concepts and algorithm mainly presented by Kirschen *et. Al* (1997) and Kirschen and Strbac (1999).

Review on Consepts and Algorithm

Based on the active or reactive branch flows from a solved power flow, the proposed method organizes the busses and branches of the network into homogeneous groups according to afew concepts which are listed below.

Contribution Generator Into Loads and Energy-Flows

Tracing the relationship between generator and load using a load flow analysis could be difficult to realize because the changing on a demand or generation for every node will produce the changing induced on generation which produced by a swing-bus. It is only possible to determine the relationship between generator (load) and the flow in the lines by determining whether the changing on generating/demand from nodes will influence on the flow on a certain lines (Rudnik *et al*, 1995). The ideas of electricity tracing have been studied by using an assumption that the sharing inflow of the nodes is divided proportionally among the outflow of the nodes. One of them is the *common* method.

Based on the active and reactive branch flows from a solved power flow, the *common* method will categorize buses and branches within the networks into several groups. Those are (1) *Domain of Generators* is defined as the set of buses which are reached by power produced by this generation; (2) power from a generator reaches a particular bus if it is possible to find a path through the network from the generator to the bus for which the direction of travel is always consistent with the direction of the flow as computed by a power flow program; (3) c*ommons* is defined as a set of contiguous buses supplied by the same generators. Unconnected sets of buses supplied by the same generators are treated as separate commons. A bus therefore belongs to one and only one common. The rank of a common is defined as the number of generators supplying power to the buses comprising this common; (4) *links* is one or more external branches connecting the same *common* form; (5) *state graph* is the state of the system can be represented by a directed, acyclic graph; *common* are represented as nodes and *links* as branches.

To obtain the contribution to the load of a common, it is required a definition of the nflow and the outflow of commons. The inflow of a common is defined as the sum of the power injected by sources connected to buses located in this common and of the power imported in this common from other commons by links. The outflow of a common is equal to the sum of the power exported through links from this common to commons of higher rank. The inflow of a common is equal to the sum of its outflow and of all the loads connected to the buses comprising the common.

The requirement assumptions are:

- *For a given common, if the proportion of the inflow which can be traced togenerator i* is x_i*, then the roportion of the outflow which can be tracedto generator i is also* x_i **.**
- *For a given common, if the proportion of the inflow which can be traced to generator i* is $\mathbf{x}$ *then the proportion of the load which can be traced to generator i is also* $\mathbf{x}_i$.

The equation of contribution generator into load of a common are:

$$F_{ijk} = C_{ij} * F_{jk} \quad (1)$$

$$Ik = \Sigma_j F_{jk} \quad (2)$$

$$C_{ik} = \frac{\Sigma_j F_{ijk}}{IF_k} \quad (3)$$

where $C_{ij}$and $C_{ik}$are contribution generator i into loads and outflow of the *common j* dan k, respectively.F_{jk} and F_{ijk} are the flows at the *link* between *common- j* and *k* and the flows at *link between common j* and *k*, respectively.

This assumption provides the basis of a recursive method for determining the contribution of ech generator to the load in each common and the proportion of the outflow traceable to each of these generators can therefore be readily computed and propagated to common of higher rank. The flowchart for determining the contribution generator into load and line flow is described at Figure 1.

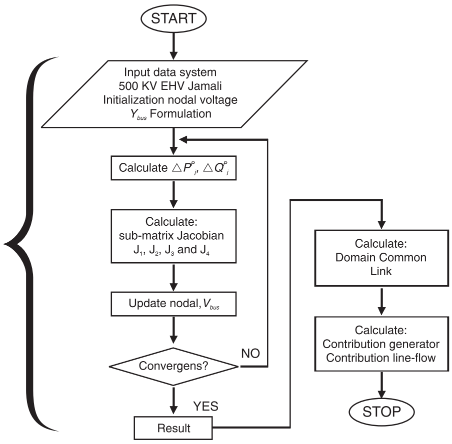

Figure 1 Flowchat representing the contribution generator method

System Study and Results

In this paper an equivalent 9-bus (Fig. 3), a part of 500 KV Jamali System (Fig. 2), is considered for studies. The system has 4 generating stations at Tanjung Jati-B, Gresik, Grati and Paiton. These generators have total capacitty of 4,506 MW of real power. The total load present in the system is 3,626 MW. The power flow in the lines are obtained for the base configuration from using the power flow algorithm (EDSA 2000 based on Fast-Decoupled algortihm) and are given in Table (1). The Data at Tabel (1) only shows current capacity on the single phase. In order to determine the energy flow at 3-phase lines, it is necessary to use a 3 x*V* x *I* formula.

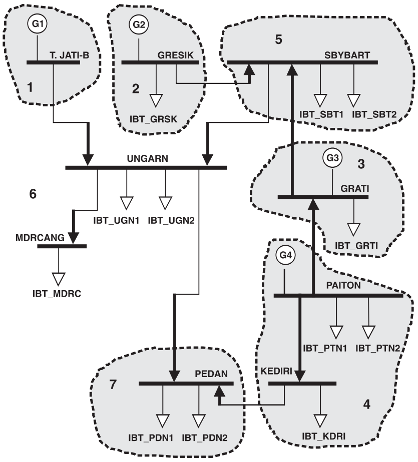

Figure 2. Single line diagram of 9-bus equivalent, a part of 500 KV Jamali system

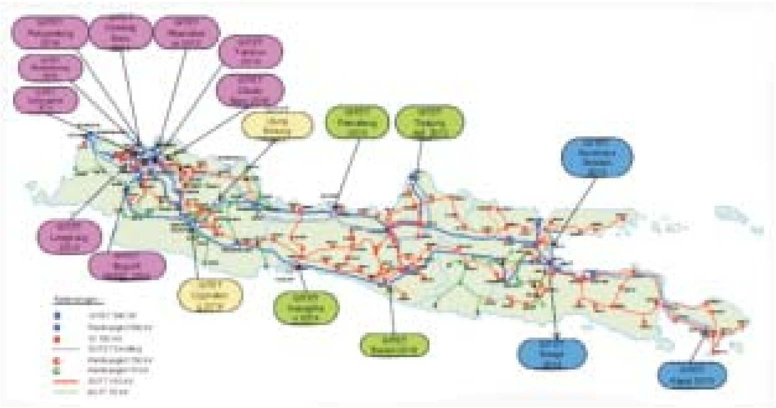

Figure 3

Single line diagram of 500 KV Jamali Interconection Lines (RUPTL, 2010)

Combining the datas at Table (1) and (2) can give the flowing energy capacity at every line which is described at Figure (4). Table (3) gives the information about *domain*. Table (4) describes about *common* number, *rank* and its group *buses*.

Table 1 The phase currents and sequence currents

No	From Bus	To Bus	I (a) A	I (b) A	I (c) A	I (0) A	I (1) A	I (2) A
1	G1_TJT-B	TJATI-B	1213	1209	1209	1	1210	2
2	G2_GRESK	GRESK	1026	1022	1021	2	1023	1
3	G3_GRATI	GRATI	481	480	479	1	480	1
4	G4_PAITN	PAITON	1400	1400	1400	1	1401	2
5	GRATI	IBT_GRTI	275	275	274	0	275	0
6	GRESK	PAITON	464	464	464	0	464	0
7	GRESK	IBT_GRSK	275	274	274	0	275	0
8	GRESKI	SBYBART	759	755	754	1	756	2
9	KEDIRI	IBT_KDRI	361	359	359	0	359	1
10	MDRCANG	IBT_MDRC	326	324	324	1	325	2
11	PAITON	IBT_PTN1	243	243	243	0	243	0
12	PAITON	IBT_PTN2	251	250	250	0	250	0
13	PAITON	KEDIRI	546	543	543	1	544	1
14	PEDAN	IBT_PDN1	333	331	331	0	332	1
15	PEDAN	IBT_PDN2	333	331	331	0	332	1
16	PEDAN	KEDIRI	186	184	184	0	185	0
17	SBYBART	GRATI	492	491	491	0	492	0
18	SBYBART	IBT_SBT1	451	450	450	0	450	1
19	SBYBART	IBT_SBT2	412	411	411	0	411	0
20	SBYBART	UNGARN	355	353	353	1	353	1
21	TJATI_B	UNGARN	1213	1209	1209	1	1210	2
22	UNGARN	IBT_UNG1	317	316	316	0	316	1
23	UNGARN	IBT_UNG2	345	343	343	0	344	1
24	UNGARN	MDRCANG	326	324	324	1	325	1
25	UNGARN	PEDAN	481	478	478	1	479	1

Tabel 2 The average voltages

No.	Bus	Type	Volt (V)	Voltage drop (%)	UNBAL (%)	UNBALΔ (%)
1	G1_TJT-B	GPV	288675	0.00	0.00	0.00
2	G2_GRESK	GPV	288675	0.00	0.00	0.00
3	G3_GRATI	GPV	288675	0.00	0.00	0.00
4	G4_PAITN	S	288671	0.00	0.00	0.00
5	GRATI	GPV	288667	0.00	0.00	0.00
6	GRESK	GPV	288659	0.01	0.00	0.00
7	IBT_GRESK	L	288659	0.01	0.00	0.00
8	IBT_GRATI	L	288667	0.00	0.00	0.00
9	IBT_KDRI	L	258878	10.32	0.20	0.08
10	IBT_MDRC	L	242523	15.99	0.37	0.15
11	IBT_PDN1	L	249309	13.64	0.28	0.11
12	IBT_PDN2	L	249309	13.64	0.28	0.11
13	IBT_PTN1	L	288659	0.01	0.00	0.00
14	IBT_PTN2	L	288659	0.01	0.00	0.00
15	IBT_SBT1	L	282913	2.00	0.03	0.01
16	IBT_SBT2	L	281913	2.00	0.03	0.01
17	IBT_UNG1	L	258263	10.54	0.21	0.08
18	IBT_UNG2	L	258263	10.54	0.21	0.08
19	KEDIRI	N	258878	10.31	0.20	0.08
20	MDRCANG	N	242523	15.99	0.37	0.15
21	PAITON	N	288659	0.01	0.00	0.00
22	PEDAN	N	249310	13.64	0.28	0.11
23	SBYBART	N	282913	2.00	0.03	0.01
24	TJATI_B	N	288663	0.00	0.00	0.00
25	UNGARN	N	258263	10.54	0.21	0.08

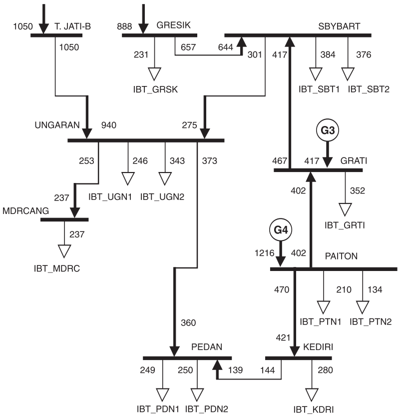

Figure 4. The energy flow at Region III and IV of the 500 KV Jamali System

Tabel 3 *Domain* information of Regional II and IV of the 500KV Jamali system

Generator name	Domain dari Generator
G1_T.JATI-B	T.JATI-B, UNGARN, MDRCANG, PEDAN
G2_GRESK	GRESK, SBYBART, UNGARN, MDRCANG, PEDAN
G3_GRATI	GRATI, SBYBART, UNGARN, MDRCANG, PEDAN
G4_PAITON	PAITON, KEDIRI, GRATI, SBYBART, UNGARN, MDRCANG,PEDAN

Tabel 4 Information of *common* number, *rank* and its *bus* buses

No. *Common*	1	2	3	4	5	6	7
Rank	1	1	2	1	3	4	4
Bus	T. Jati-B	Gresik	Grati	Paiton	SBY	Ungarn	Pedan
				Kediri	Bart	Mdrcang	

Figure (7) is the *lossles* lines of the Region II and IV of the 500 KV Jamali system. At Figure (8) , it is showed how the Region II and IV of the 500 KV Jamali system grouped into several *commons*. Table (5) shows the generating capacity and its load; and Tabel (6) displays the information about *link*. The *state-graph* diagram of the regions II and IV of the500 KV Jamali is given at Figure (7).

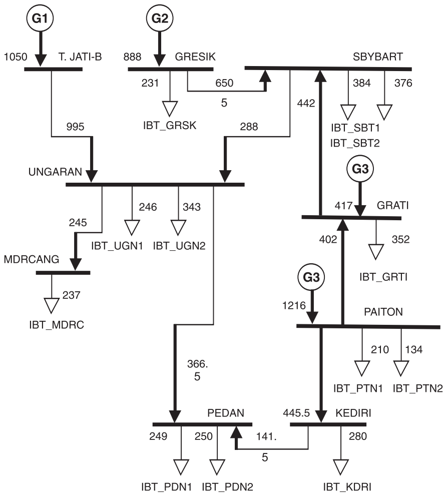

Figure 5

The energy flow *lossless* at Region III and IV of the 500 KV Jamali System

Table 5 Generating capacity and its load (P3B, 2009)

Bus	Real Power (MW)	
Name	Generating	Load
GRATI	417	352
GRESIK	417	352
KEDIRI	-	280
MDRCANG	-	237
PAITON	2784	344
PEDAN	-	499
SBYBART	-	760
T.JATI-B	888	231
UNGARN	-	589

Tabel 6 Information about *link*

No. *Link*	From *Common*	To *Common*	*Link* flow (MW) Forward flow - Backward Flow
1	1	6	1050 - 940
2	2	5	657 - 644
3	3	5	467 - 417
4	4	3	402 - 402
5	4	7	144 - 139
6	5	6	301 - 275
7	6	7	373 - 360

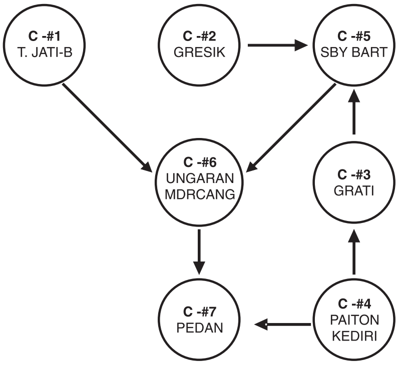

Figure 7 Diagram *State Graph* Sistem SUTET 500KV Jawa Reg. III & IV

The generator contribution factor towards loads and flow in *common* is solved by using the equation (3). The contribution of G2_GRESK towards loads and flow in *common* # 5 is $C_{G2\_GRESK\ .5} = \frac{total}{644 + 417} = 0{,}595$

The total contribution of generators is shown at Table (12).

Tabel 12 Generator contribution to "the load in each *common*" and "flow from the *common*"

	Nomor *Common*						
Nama Generator	1	2	3	4	5	6	7
G1_T.JATI-B	1	0	0	0	0	0,776	0,560
G2_GRESK	0	1	0	0	0,596	0,134	0,097
G3_GRATI	0	0	0,509	0	0,206	0,046	0,034
G4_PAITON	0	0	0,491	1	0,198	0,044	0,309

From the Table (6), it is shown that the highest voltage drop rised at MDRCANG bus which is a Northern-lines transmission system connecting the BDGSLTN bus. Meanwhile, the second highest voltage drop is in the Southern-lines at the bus of PEDAN. This condirions show that the division of energy transfer within those lines have already reached the goal (the loads is divided into the similar portion, even tough the bigger portion flows through the Northern-lines). It is also said that the effectivity of the energy flows are on the right tract. Because the portion of the Northern-lines is bigger than the Southern-lines, the unbalance voltage drop occured at the Southern-lines (at MDRCANG bus).

Tabel (12) shows the *common* no. 6 (UNGARN and MDRCANG buses) and no. 7 (PEDAN bus) have the highest portion of generator contribution. Both *commons* are "the gate" of the Northern-lines and the Southern-lines. The highest portion of its energy are supplied by the T.Jati-B power station and shows that its generator capacity is very significant to contribute the energy sent into the Region-I. By increasing the capacity of T.Jati-B's generator, the transmission loss during the process of energy distribution into the Region I could be decreased compared to way while the capacity product of the Paiton is increased. This situation is occured because the distance from T.Jati-B power station to the Region-I less than the distance from Paiton power station to the Region I.

Conclusion

In this paper a case study on transmission line utilization by individual generators is illustrated with the equivalent 9-bus system, a part of the 500 KV Jamaly System. The presented concepts are better suited to find the utilization of resources generation/load and network by PT. PLN as a state-own electricity operator involved in the day-to-day operation of the system under normal condition. For example, to supply the demand at PEDAN *IBT* it should be to operate G1_T.JATI-B power station more than any other station. And then, to supply all loads of SBYBART *IBT* as the electricity load of Surabaya City it shoud also be clear that the generator loaded is G2_GRESIK. To fulfill the demand capacity of the Region-I as the centre of urban industry in Jamali areas it would benefit to consider the portion base of generator contribution towards loads and energy flows.

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