

PNOC-EDC'S 42-MWE WIND POWER GENERATION PROJECT IN ILOCOS NORTE

SYSTEM IMPACT STUDY

1. BACKGROUND

PNOC-EDC is currently preparing the design specifications for its 42-MWe Wind Power Generation project to be located in Ilocos Norte, a province in the northern part of Luzon Island. In connection with their current activities, PNOC-EDC has requested NPC to do a System Impact Study for the project.

In particular, PNOC-EDC requested NPC to do a power system simulation study to investigate the system performance of the inductive generators to be used for the wind power project. Attachment A shows in detail the scope of work of this System Impact Study. The proposed power generation project, which will consist of wind turbine driven induction generator units, is scheduled for commercial operation by year 2002.

Adopting the latest load forecast and the 1999 Power Development Program as the reference plan, NPC conducted the required analyses, such as loadflow and stability studies as well as short-circuit study. These studies were necessary to determine the adequacy of the power grid and the interconnection for the 42-MWe Wind Power Project. Whenever necessary, reinforcement facilities and power conditioning devices were introduced to ensure the feasible operation of the proposed power plant.

2. METHODOLOGY

The PDP, which contains the long-term generation and transmission expansion plans of NPC, was used to establish the system conditions for the period the proposed PNOC-EDC Wind Power Project will be operational. The latest demand forecast was also adopted to take into account the future load growth of the entire power grid by 2002.

These projected system conditions provided inputs to computer simulation studies (i.e., loadflow, stability and short-circuit calculations) for the Luzon Grid to determine the impact of the entry of the 42-MWe PNOC-EDC Wind Power Project.

The results of the power system simulation studies were evaluated against a set of planning criteria to determine if the operation of the wind power generation project would not result to transmission line overloads, instability or other system constraints.

Grid reinforcements or improvements were introduced in the simulation studies in cases when the existing system and planned expansions fail to meet conditions in the transmission planning criteria. These reinforcements or improvements are in the form of new transmission and substation facilities as well as power conditioning devices such as capacitor banks. The corresponding budgetary estimates for the required reinforcements or improvements were prepared for economic evaluation purposes.

3. PROJECTED SYSTEM CONDITIONS

3.1 Demand Projection

The projected coincident peak demand of Luzon used in the simulation studies was 6,162 MW by year 2002. This was based on the latest market analysis conducted by NPC where an annual average growth rate of 7% was considered for the period 2000 to 2002. The total projected demand was allocated based on the existing geographical distribution: 20% for the northern region, another 20% for the southern region, and the remaining 60% in the Metro-Manila area.

In particular the load in the Ilocos and La Union provinces account for about 2% of the total demand of the whole island, the corresponding load distribution of which is shown in Table 1.

Table 1. Ilocos and La Union Provinces
Existing and Projected Substation Loads.

SUBSTATIONS	LOADING, MW	
	2000	2002
Total Load of Ilocos Region	51.9	59.5
Laoag	14.9	17.1
Currimao	7.7	8.8
Bantay	12.1	13.9
San Esteban	17.2	19.7
Total Load of La Union	47.0	53.9
Bauang	47.0	53.9

3.2 Generation Expansion and Dispatch Schedules

The reference plan used in the power system simulation study is the 1999 Power Development Program, the latest official plan issued by NPC to date. Although the 2000 Power Development Program is under preparation, this reference is still valid since the planned generation projects for the period 2000 to 2005 will not have significant impact on the northern portion of the transmission system. Moreover, if there would be changes in the generation line-up, its impact will be more on the generation mix (i.e., type of fuel).

The generation projects identified in the 1999 Power Development Program for the period 2000-2002 were included in establishing reference system condition (please refer to NPC's 1999 Power Development Program for details on the generation expansion plan). These generation expansion plans include MERALCO IPPs. Table 2 summarizes the generation projects in Luzon which are scheduled for commissioning for the period 2000-2005. Note that the additional generation projects are intended to supply additional power requirement of Metro-Manila and nearby load centers.

The corresponding generation dispatch schedules used in the simulation studies are shown in Table 3 and 4. These dispatch schedules include the proposed 42-MWe Wind Power Project. The generation dispatch schedules which are referred to as maximum south and maximum north generation dispatches were considered in the analysis to simulate maximum power transfer from Northern Luzon as well as from Southern Luzon, which reflects large transmission loading at normal condition.

These generation dispatch scenarios were modeled to simulate the worst expected normal operating modes of the power system. In particular, each generation dispatch scenario would test the strength of each transmission corridor in terms of power transfer capability, voltage stability, and system stability.

Table 2. Partial List of Luzon Generation Projects
for the Period 2000-2005

Plant Description	Capacity (MW)	Location Of Plant	Commissioning Date
Casecnan	140	Pangasinan	2001
Ilijan Natgas	1200	Batangas	2002
FGPC San Lorenzo*	500	Batangas	2002
San Pascual Cogen	300	Batangas	2002

San Roque	345	Pangasinan	2004
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* MERALCO IPPs

Table 3. Maximum North Generation Dispatch
Planning Year 2002

Plant Description	Rated Capacity (MW)	Dispatched Capacity (MW)
North Generation	3534	3313
PNOG-EDC Wind Turbine	40	40
Magat Hydro	360	360
Bakun Hydro	70	70
Ambuklao Hydro	75	75
Binga Hydro	100	100
Sual Coal	1000	983
Bauang Diesel	212	200
Masinloc Coal	600	600
Pantabangan Hydro	100	100
Masiway Hydro	9	9
Enron Subic	110	110
Bataan EPZA	58	16
Limay CC-A	300	294
Limay CC-B	300	294
Angat Hydro	200	62
Metro-Manila Generation	2720	888
Malaya Thermal	650	200
Malaya GT	90	0
Sucac Thermal	850	180
MCI Diesel	48	48
Manila Thermal	200	0
Sabah Diesel	120	0
Duracom Diesel	132	100
Hopewell GT	280	280
VDHorst GT	80	80
Navotas PB	150	0
FELS	120	0
South Generation	4458	2143
Kalayaan Pump Storage	300	100
Pagbilao Coal	700	300
Quezon Coal	440	0
Caliraya Hydro	32	32
Botocan Hydro	11	11
Makban Geothermal	370	330
Sta Rita Nat Gas	1000	300
Calaca Coal	600	500
Enron Pinamucan	105	0
Tiwi Geothermal	330	0

BacMan Geothermal	110	110
Cawayan Hydro	20	20
Leyte Geothermal	440	440

Table 4. Maximum South Generation Dispatch
Planning Year 2002

Plant Description	Rated Capacity (MW)	Dispatched Capacity (MW)
North Generation	3534	1270
PNOG-EDC Wind Turbine	40	40
Magat Hydro	360	90
Bakun Hydro	70	70
Ambuklao Hydro	75	25
Binga Hydro	100	50
Sual Coal	1000	368
Bauang Diesel	212	44
Masinloc Coal	600	300
Pantabangan Hydro	100	50
Masiway Hydro	9	0
Enron Subic	110	15
Bataan EPZA	58	16
Limay CC-A	300	70
Limay CC-B	300	70
Angat Hydro	200	62
Metro-Manila Generation	2720	888
Malaya Thermal	650	200
Malaya GT	90	0
Sucat Thermal	850	180
MCI Diesel	48	48
Manila Thermal	200	0
Sabah Diesel	120	0
Duracom Diesel	132	100
Hopewell GT	280	280
VDHorst GT	80	80
Navotas PB	150	0
FELS	120	0
South Generation	4458	4184
Kalayaan Pump Storage	300	300
Pagbilao Coal	700	700
Quezon Coal	440	200
Caliraya Hydro	32	32
Botocan Hydro	11	17
Makban Geothermal	370	330
Sta Rita Nat Gas	1000	1000
Calaca Coal	600	600
Enron Pinamucan	105	105

Tiwi Geothermal	330	330
BacMan Geothermal	110	110
Cawayan Hydro	20	20
Leyte Geothermal	440	440

3.3 Transmission Expansion

Complementary to the generation expansion plan, several transmission facilities that are scheduled for completion within the period 2000-2002 are incorporated in the model. These transmission facilities are part of the reinforcement requirement of the Luzon transmission system to support NPC's capacity build-up as well as serving various transmission service agreements with IPPs selling power directly to bulk customers.

Shown in Table 5 are the reinforcement facilities for the northern Luzon transmission corridor as well as plans for reinforcing the Metro-Manila power delivery facilities. Included also in the table are the reinforcement plans for the Bauang-Sn Esteban and Sn Esteban-Laoag lines.

Table 5. Partial List of Transmission Line Projects

PROJECT DESCRIPTION	PDP TARGET COMPLETION
1. Dasmariñas-Zapote Transmission Project <ul style="list-style-type: none"> Imus-Zapote, 9.946 km, 230-kV SPDC 4-795 MCM Zapote S/S, 3-300- MVA XFMR, 230/115-KV 	2001 ¹ 2000 2001
2. Ilijan NGAS Generation Associated T/L <ul style="list-style-type: none"> Cut-in Tayabas-Dasmariñas, 58 km., 500-kV STDC 4-795 MCM Tayabas S/S Upgrading, 3-600 MVA 500/230 Kv Xfmer Dasmariñas S/S Upgrading, 3-600 MVA 500/230 kV xfmer 	2002 ¹
3. 230 kV T/L Upgrading Projects-1 <ul style="list-style-type: none"> Sn Manuel-Concepcion-Mexico, 117kms., 230-kV STDC 2-795 MCM 	2004 ²
4. Bauang-San Esteban L2 Stringing Project <ul style="list-style-type: none"> 95 kms, 230-kV 1-795 MCM ckt 	2004 ²
5. Sn Esteban-Bantay-Laoag 230-kV Project (initially energized at 115kV) <ul style="list-style-type: none"> 120 kms, 230-kV 1-795 MCM STDC 	2005 ²

1 Engineering completion target as of October 2000

2 PDP completion target

This scheme specifies a 115-kV connection for the PNOC-EDC Wind Power Project at Burgos, Ilocos Norte directly to the existing NPC's 115-kV substation in Laoag. The delivery of the 42-MWe PNOC-EDC Wind Power output is via within 40-kms 115-kV double-circuit line. The conductor can be either 1-336.4 MCM or 1-795 MCM and selection will depend on the economics and the future expansion of the wind farm.

From Laoag substation, the output of the 42-MWe Wind Power is intended for delivery to the electric cooperatives in the Ilocos province. This would entail the use of the Laoag-Currimao-Bantay-Sn Esteban 115-kV transmission corridor. Refer to Figure 1 for the corresponding single-line diagram and Figure 2 for the development map shown in the appendix. The transmission corridor from Laoag to Sn Esteban is further connected to the rest of Luzon grid via the existing Sn Esteban-Bakun-Bauang 230-kV corridor.

At present, the power requirement of the provinces of La Union and Ilocos is being supplied from the grid. Although the existing 150-MVA Sn Esteban-Laoag transmission is still adequate, low bus voltages occurs at the furthest end of the corridor. This is due to the significant distance (about 220-kms) from the grid. Since this is a single-circuit line, there is no redundancy for single-outage contingencies. This implies that loss of the line will result in total isolation of the area. This is the reason for introducing a second circuit from San Esteban all the way up to the PNOC-EDC plant in Ilocos Norte.

3.4.2. 230-kV Connection To Laoag

This scheme specifies a double-circuit 230-kV connection for the PNOC-EDC Wind Power to Laoag substation. This will mean the completion of the 120-km Laoag-Sn Esteban 230-kV circuit and substation upgrading at the existing Laoag 115-kV substation will be necessary for the commissioning of PNOC-EDC Wind Power Project. The 230-kV connection scheme is shown in Figure 1 while its corresponding development map is shown in Figure 2.

Although more reliable, the 230-kV scheme is not economically attractive due to high first cost and low utilization rate. Should PNOC-EDC decide to construct the PNOC EDC-Laoag associated line for 230-kV application the line can be initially energized at 115-kV pending completion of the Laoag-Sn Esteban 230-kV line. As soon as the Laoag-Sn Esteban 230 kV line is completed, the PNOC-EDC associated line can be shifted to 230-kV by changing the step-up transformers at the plant side.

4. TRANSMISSION PLANNING CRITERIA

The adequacy of the grid to transfer power from the wind farm plant to the provinces of Ilocos and La Union and the rest of the Luzon 230-kV network was determined by evaluating the simulation results against a set of transmission planning criteria. Table 6 is the summary of the criteria being adopted by NPC. The criteria considers single-line outage contingencies, which based from the operating experience of NPC is sufficient to obtain reliable transmission performance.

Table 6. Summary of Planning Criteria

ACCEPTABLE LIMITS		ALLOWABLE REMEDIAL ACTION
Normal Conditions		
Transmission line loading:	< 100%	Line reinforcements
Transformer loading:	< 100%	Transformer additions
Steady-state voltage range:	± 5%	Reactive power dispatch or compensation
Single Outage Contingencies		
Transmission line loading:	< 110% (new)	Line reinforcements
Transformer loading:	< 110% (new)	Transformer additions
Steady-state voltage range:	± 10%	Reactive power dispatch or compensation
Transiently stable for 3phase fault w/ normal clearing		Appropriate reinforcements/devices

In cases when the simulation studies fail to meet the transmission planning criteria, grid reinforcements or improvements were introduced in the form of additional transmission, substation facilities or power conditioning devices such as capacitor banks.

5. ECONOMIC ASSUMPTIONS

The budgetary cost estimates for the required transmission reinforcement facilities are based on 1999 price levels. The cost patterns were gathered and extracted by our Engineering Group from previous project cost estimates as well as from completed and ongoing projects contracts. The estimated unit costs for the transmission lines and terminal equipment are summarized in Table 7 below. The exchange rate applied to get the total

cost in US dollars is PHP50 to 1USD. Other parameters used in the economic analysis are shown in Table 8.

Table 7. T/L and Substation Unit Cost Estimates

System Voltage KV	Description	Estimated Cost		
		Forex, M\$	Local, MP	Total, M\$
115	1-336.4 MCM STSC	0.048	0.580	0.0596
115	1-795 MCM STSC	0.064	0.836	0.0807
115	1-795 MCM STDC	0.095	1.141	0.1178
230	1-795 MCM STSC	0.069	1.331	0.0956
230	1-795 MCM STDC	0.103	1.589	0.1348
230	2 nd 1-795 MCM ckt stringing	0.020	0.108	0.0222
230	50-MVA XFMR 230/115-kV	0.912	6.126	1.0345
230	PCB + ACCESSORIES	0.129	0.868	0.1464
115	PCB + ACCESSORIES	0.114	0.768	0.1294
115	5-MVAR Capacitor bank @ \$10/kVA **	0.050	0.112	0.0522

** - excluding switching devices

Table 8. Economic Parameters

Parameter	Assumed Value
Annual Interest Rate, %	12%
Economic Life, years	30 years
Selling Cost of Electricity, P/kWh	P3.00 / kWh
O&M Cost, % of Total Cost	5%

6. MODEL ADOPTED AND SIMULATION TEST PROCEDURE

6.1 The Wind Turbine-Generator Model

The model adopted in the simulation studies was derived from the data sheet provided for the wind-turbine generators. The unit rating for each generator used in the study is 700-kW at 0.87 power factor at full load without reactive compensation. The corresponding reactive consumption of each unit is 400-kVar. Each unit is equipped with a 250-kVar fixed capacitor to support the reactive requirement of each circuit. The 42-MWe Wind Power Project will consume about

23 MVAR while the compensation provided by the fixed capacitors will be about 13 MVAR.

The machine reactances as derived from the data sheet were fitted using a standard induction generator model supplied within the PSS/E software. The data sheet and the computed equivalent parameters are shown in the appendix.

6.2 Simulation Procedure

The study considered simulation runs to determine the performance of the 42-MWe Wind Power Project and its effect on the entire system during steady-state and dynamic conditions. The simulations include loadflow and stability analyses for the different connection schemes.

The specific objective of the loadflow simulations is to determine the thermal adequacy of the transmission system and the steady-state MVAR compensation requirement to maintain bus voltages within acceptable limits. The test involved simulations of maximum generation dispatches from north and south with sensitivity analysis on the effect of Bakun Hydro on the system voltage profile. The tests considers the simulation for normal condition where all circuits are energized and during single-line outage (n-1) conditions.

The dynamic analyses will determine the stability performance of the PNOG-EDC induction generators as affected by faults or switching actions in the transmission system. The simulation objective is to determine the additional power-conditioning requirement such as MVAR compensation in order to improve the machine stability as well as to correct voltage during disturbances. Dynamic analyses were done for both connection alternatives. In particular, while the 42-MWe Wind Power Project is operating at different system conditions, the following simulations were carried out:

- 100-ms three-phase fault at Sn Esteban 230-kV bus and Laoag Bus followed with fault clearing by opening the Bauang-Sn Esteban second circuit and Laoag-Sn Esteban Line 2, respectively.
- Tripping of a 700-kW Wind Turbine Induction Generator.
- Synchronizing the last 700-kW Wind Turbine Induction Generator.

7. RESULTS OF THE STUDY

The following are the results of the various computer simulation studies using different system conditions for 2002:

7.1 LOADFLOW ANALYSIS

Load flow simulations were conducted based on the system conditions generated for the planning year 2002. Specifically the simulation runs were conducted to analyze the impact of generation dispatch on the thermal loading of the transmission corridor and voltage profile of each substation bus. The overall goal is to test the system performance to conform with the single-circuit outage contingency (n-1) criteria. Necessary remedial measures and/or reinforcement facilities were identified to maintain the system within operational limits during normal and emergency conditions.

7.1.1 SYSTEM CONDITION (YR 2002) PRIOR TO THE ENTRY OF 42-MWE PNOC-EDC WIND POWER GENERATION PLANT

To establish the base case system conditions, the load flow scenarios prior to the entry of the 42-MWe PNOC-EDC Wind Power Project were simulated. This would more or less enable us to determine the transmission line loading level and bus voltage profiles to serve as benchmarks for the succeeding load flow scenarios. For this system condition, the same generation dispatches shown in Table 3 and 4 above were used except that the wind farm generation is not operating.

The maximum north generation dispatch scenario was simulated to determine the load levels on each transmission line within the northern Luzon transmission corridor as this would impact on the transmission line adequacy and bus voltage profiles.

Before the commissioning of the 42-MWe PNOC-EDC Wind Power Project, the power requirement of Ilocos and La Union provinces is drawn from the grid at Sn Esteban. Since the load requirement of each region is still within the line ratings, no overloading is expected. Although this is the case, the line corridor has no allowance for (n-1) contingency and during permanent outage the line would isolate the entire area of Ilocos.

Due to the long distance between the power supply point at Bauang and the farthest load point at Laoag, a significant voltage drop is expected although would still fall within the minimum acceptable voltage limit of 0.95 per unit. Refer to Table 9 for the load flow results. The power flow diagrams are shown in the appendix.

The loading impact of the maximum south generation dispatch would not affect the Bauang-Sn Esteban and Sn Esteban-Bantay-Currimao-Laoag line performance. Its effect is on other part of the Luzon grid particularly the southern corridor. However, the voltage profile in the provinces of concern are expected to change due to the redistribution of MW as well as MVar supply. Again, the voltage profiles are within the acceptable limits. Refer to Table 9. The power flow diagrams are shown in the appendix.

To simulate the effect of single-line outage (n-1) contingencies on voltage stability, the Bauang-Sn Esteban 230-kV line 2 was assumed energized as a minimum requirement. The resulting powerflows and voltage profiles are also shown in Table 9 and in the details of the power flows in the appendix.

Table 9. Summary of Loadflow Results
a. Maximum North Generation Dispatch

CONTINGENCY EVENT	AFFECTED ELEMENTS		LOADING NORMAL CONDITION		LOADING (N-1) CONDITION	
	CIRCUIT	RATING	MVA	%	MVA	%
A. Base Case-Existing Network						
Normal Condition	Sn Esteban-Bantay	150	43	29	Isolated	
	Bantay-Currimao	150	30	20	Isolated	
	Currimao-Laoag	150	20	13	Isolated	
B. W/ PNOG-EDC Wind Power Project- 115kV Connection						
All required facilities in	PNOG EDC-Laoag L1	150	20	13		
	Laoag-Sn Este 115kV	150	7	5		
	Laoag-Currimao 115kV	150	17	12		
	Buang-Sn Este 230kV	300	10	4		
	Bakun-Sn Este 230kV	300	32	11		
Out PNOG EDC-Laoag L1	PNOG EDC-Laoag L2	150	20	13	41	27

Out Laoag-Sn Este 115kV	Laoag-Currimao 115kV	150	17	12	24	16
Out Bau-Sn Este 230kV	Bakun-Sn Este 230kV	300	32	11	29	10
C. w/ PNOG-EDC Wind Power Project-230kV Connection						
All required facilities in	PNOG EDC-Laoag L1	300	20	7		
	Laoag-Sn Este 230kV	300	27	9		
	Laoag-Currimao 115kV	150	9	6		
	Buang-Sn Este 230kV	300	10	4		
	Bakun-Sn Este 230kV	300	29	10		
Out PNOG EDC-Laoag L1	PNOG EDC-Laoag L2	300	20	13	41	13
Out Laoag-Sn Este 230kV	Laoag-Currimao 115kV	150	9	6	24	8
Out Bau-Sn Este 230kV	Bakun-Sn Este 230kV	300	10	4	19	6

STATION	Bus Voltages @ Different Contingencies, in pu					
	w/o PNOG EDC	w/ PNOG-EDC WP				
	N	n, w/o cap	n, w/ cap	(n-1)	(n-1)'	(g-1)
B. PNOG-EDC 115-kV Connection						
Buang 230-kV	0.970	0.969	0.973	0.970	0.973	0.968
Bakun 230-kV	0.980	0.978	0.985	0.982	0.985	0.970
Sn Esteban 230-kV	0.965	0.961	0.976	0.971	0.976	0.966
Sn Esteban 115-kV	1.022	0.977	1.010	1.007	1.011	1.002
Bantay 115-kV	0.991	0.951	0.999	0.997	0.998	0.993
Currimao 115-kV	0.956	0.923	0.991	0.989	0.987	0.987
Laoag 115-kV	0.943	0.913	0.991	0.990	0.986	0.989
Laoag 230-kV	-	-	-	-	-	-
PNOG-EDC 115-kV	-	0.909	1.000	1.000	1.000	1.000
PNOG-EDC 230-kV	-	-	-	-	-	-
C. PNOG-EDC 230-kV Connection						
Buang 230-kV	0.970	0.973	0.977	0.973	0.973	0.973
Bakun 230-kV	0.980	0.985	0.992	0.992	0.985	0.981
Sn Esteban 230-kV	0.965	0.975	0.990	0.993	0.977	0.983
Sn Esteban 115-kV	1.022	1.009	1.027	1.031	1.013	1.020
Bantay 115-kV	0.991	0.990	1.013	1.016	1.002	1.006
Currimao 115-kV	0.956	0.970	0.999	1.002	0.992	0.992
Laoag 115-kV	0.943	0.964	0.996	0.999	0.993	0.996
Laoag 230-kV	-	0.970	1.007	1.010	1.007	1.002
PNOG-EDC 230-kV	-	0.967	1.009	1.011	1.008	1.004
PNOG-EDC 115-kV	-	0.914	1.000	1.000	1.000	1.000

Legend: n- normal; (n-1) - Bau-Sn Este Lout ; w/o cap – no reactive compensation; w/cap – with reactive compensation; (n-1)' –Laoag-Sn Este Lout; (g-1)- Bakun hydro out

b. Maximum South Generation Dispatch

CONTINGENCY EVENT	AFFECTED ELEMENTS		LOADING NORMAL CONDITION		LOADING (N-1) CONDITION	
	CIRCUIT	RATING	MVA	%	MVA	%
A. Base Case-Existing Network						
Normal Condition	Sn Esteban-Bantay	150	43	29	Isolated	

	Bantay-Currimao	150	30	20	Isolated	
	Currimao-Laoag	150	20	13	Isolated	
B. w/ PNOC-EDC Wind Power Project- 115kV Connection						
All required facilities in	PNOC EDC-Laoag L1	150	20	13		
	Laoag-Sn Este 115kV	150	7	5		
	Laoag-Currimao 115kV	150	17	12		
	Bauang-Sn Este 230kV	300	10	4		
	Bakun-Sn Este 230kV	300	32	11		
Out PNOC EDC-Laoag L1	PNOC EDC-Laoag L2	150	20	13	41	27
Out Laoag-Sn Este 115kV	Laoag-Currimao 115kV	150	17	12	24	16
Out Bau-Sn Este 230kV	Bakun-Sn Este 230kV	300	32	11	29	10
C. w/ PNOC-EDC Wind Power Project-230kV Connection						
All required facilities in	PNOC EDC-Laoag L1	300	21	7		
	Laoag-Sn Este 230kV	300	26	9		
	Laoag-Currimao 115kV	150	9	6		
	Bauang-Sn Este 230kV	300	11	4		
	Bakun-Sn Este 230kV	300	9	3		
Out PNOC EDC-Laoag L1	PNOC EDC-Laoag L2	300	21	7	41	14
Out Laoag-Sn Este 230kV	Laoag-Currimao 115kV	150	26	9	24	16
Out Bau-Sn Este 230kV	Bakun-Sn Este 230kV	300	11	4	19	6

STATION	Bus Voltages @ Different Contingencies, in pu					
	w/o PNOC-EDC	w/ PNOC-EDC WP				
	n	n, w/o cap	n,w/ cap	(n-1)	(n-1)'	(g-1)
B. PNOC -EDC 115-kV Connection						
Bauang 230-kV	0.984	0.984	0.988	0.988	0.985	0.983
Bakun 230-kV	0.990	0.989	0.995	0.995	0.991	0.984
Sn Esteban 230-kV	0.977	0.974	0.986	0.987	0.978	0.979
Sn Esteban 115-kV	1.026	0.992	1.019	1.022	1.013	1.013
Bantay 115-kV	0.995	0.967	1.007	1.006	1.001	1.002
Currimao 115-kV	0.960	0.940	0.995	0.991	0.992	0.992
Laoag 115-kV	0.947	0.931	0.993	0.988	0.991	0.992
Laoag 230-kV	-	-	-	-	-	-
PNOC-EDC 115-kV	-	0.927	1.000	1.000	1.000	1.000
PNOC-EDC 230-kV	-	-	-	-	-	-
C. PNOC -EDC 230-kV Connection						
Bauang 230-kV	0.984	0.989	0.993	0.988	0.989	0.990
Bakun 230-kV	0.990	0.996	1.002	1.001	0.996	0.997
Sn Esteban 230-kV	0.977	0.989	1.002	1.001	0.989	0.998
Sn Esteban 115-kV	1.026	1.024	1.039	1.039	1.025	1.035
Bantay 115-kV	0.995	1.005	1.025	1.024	1.012	1.021
Currimao 115-kV	0.960	0.986	1.010	1.009	1.001	1.006
Laoag 115-kV	0.947	0.984	1.008	1.006	0.999	1.003
Laoag 230-kV	-	0.985	1.016	1.015	1.010	1.013
PNOC-EDC 230-kV	-	0.982	1.016	1.016	1.012	1.014
PNOC-EDC 115-kV	-	0.931	1.000	1.000	1.000	1.000

Legend: n- normal; (n-1) - Bau-Sn Este Lout ; w/o cap – no reactive compensation; w/cap – with reactive compensation; (n-1)' –Laoag-Sn Este Lout; (g-1)- Bakun hydro out

7.1.2 SYSTEM CONDITION (YR 2002) UPON THE ENTRY OF 42-MWE PNOC-EDC WIND POWER GENERATION PLANT

The entry of the 42-MWe PNOC-EDC Wind Power Project has no negative impact on the transmission line loading. There will be no significant increase on the powerflows of Sn Esteban-Bantay-

Currimeo-Laoag line except that the direction of flows will be reversed. This is due to the fact that the power requirement in the area is now coming from PNOC-EDC Wind Power Project instead of from the grid.

However, the windfarm connection will result to a significant voltage dip in the nearby buses due to large consumption of MVAr of the induction generators in the wind farm. Several conditions were analyzed to zoom in on the voltage problem emanating from the proposed connection.

Without the reinforcement line from Laoag to Sn Esteban, the bus voltage at PNOC-EDC and nearby Laoag substation will fall to 0.65 p.u. leading to voltage collapse that could lead to isolation of the area. The bus voltages are more worst during shortage of reactive power supply particularly when Bakun Hydro is out of service.

To comply with the (n-1) outage criteria and maintain voltage stability, it is necessary to reinforce the existing Laoag-Sn Esteban line. Capacitor banks of at least 25-MVAr capacity should also be provided during steady-state condition at PNOC-EDC bus to boost the bus voltage to unity. Since each wind-turbine induction generator unit is equipped with a 250-kVAR switched capacitor, a total of about 13-MVAr can be derived from it. The remaining 12 MVAr requirement should come from an additional bank located at PNOC-EDC 115-kV bus. The resulting voltage profiles are shown in Table 9 and the details of the powerflows are shown in the appendix.

Both 115-kV and 230-kV connection schemes were tested to determine their relative strength/performance in meeting the steady-state planning criteria. As shown in Table 9 and in the powerflow diagrams, slightly better voltage profiles could be obtained from a 230-kV connection. However, looking at the loading of each line, a 230-kV connection would result to lower loading. This implies that the 230-kV connection, which would not be loaded significantly, will have lower utilization rate and may not be economically justifiable for this project application.

7.2 STABILITY ANALYSIS

Dynamic simulations for both generation dispatches were conducted to verify the stability of the power system following a disturbance. The objective of the dynamic analysis is to observe the voltage stability as well as the slip stability of the induction generators to be installed at PNOC-EDC Wind Power Project during disturbance conditions. Two fault conditions for both connection schemes were

simulated, namely: fault at the Bauang-Sn Esteban 230-kV Line 2 and another fault at Laoag-Sn Esteban line. The following were the disturbance conditions considered in the dynamic analysis:

- Opening of Sn Esteban-Bauang 230-kV line 2 following a 100-ms three-phase bus fault at San Esteban 230-kV substation.
- Opening of Laoag-Sn Esteban line 2 following a 100-ms three-phase bus fault at Laoag substation. Bus voltage at Laoag is either 115kV or 230kV depending on the connection scheme considered.
- Tripping of a 700-kW Wind Turbine Induction Generator.
- Synchronizing the last 700-kW Wind Turbine Induction Generator.

3ph Fault Simulation. The fault conditions considered in the study are simulated one at a time. The 3-phase fault conditions that were investigated are one at Sn Esteban 230-kV bus and another at Laoag bus (at 115-kV and 230-kV bus depending on the connection alternative analyzed). These disturbance simulations are necessary to observe the response of the PNOC-EDC generators during line faults. For fault at Sn Esteban, the Bauang-Sn Esteban 230kV line is opened to clear the fault. For fault at Laoag, the Laoag-Sn Esteban line is opened to clear the fault.

For the Ilocos Area to remain connected to the system, the Bauang-Sn Esteban and Sn Esteban- Laoag lines are necessary for both connection alternatives. Otherwise a single-contingency outage occurring between Sn Esteban and Laoag will result in islanding or total power interruption in the area.

With reference to Table 10, an additional 20 to 40 MVARs dynamically switched capacitors at PNOC-EDC bus is required to maintain both slip stability of the induction machines and voltage stability in the area. Notice that fault nearer to PNOC-EDC bus will require the most compensation and in the case of fault at Laoag, dynamic compensation requires about 40-MVARs. For the 230-kV connection scheme, compensation requirement is more than that of the 115-kV connection. This is so because the reactance of the step-up transformers at both PNOC-EDC and Laoag contributes to the total reactance of the remaining circuits after fault clearing.

Take note that the required dynamically-switched capacitor banks is in addition to the initial 25 MVAR capacitor bank for steady state

compensation in the area. The MVAR requirement can be attributed to the large exchange of MVAR flows toward the faulted point during fault condition that eventually decays to almost zero after several cycles upon clearing of fault. The block size of each capacitor used in the simulation is a 5 MVAR per bank with automatic switching speed of 50ms.

A relatively wide range of reactive compensation level was considered in the study to simulate and show its effect on the machine and voltage stability over several generation dispatch scenarios including sensitivity runs reflecting shortage of MVar supply from nearby generators. It should be noted that with inadequate compensation, the bus voltage decays rapidly reaching a point of collapse wherein the induction generators will tend to operate at increasing slip until reaching instability point.

Tripping of one 700-kW induction generator unit or synchronizing of the final 700-kW induction generator will not significantly affect the bus voltage as well as the slip stability of the other induction generators as long as the initial 25-MVAR shunt capacitor banks are on line.

The stability plots are shown in the attachment and Table 10 tabulates the summary of results.

Table 10. Summary of Dynamic Simulations Results
(Cases w/ initial 25-MVAR Capacitor Bank at PNOC-EDC)

CASE	Ref Figure	Additional Compensation		Simulation Result		Remarks
		MVAR	SITE	Slip	Voltage	
A. PNOC-EDC 115-kV Connection Scheme						
Fault at Sn Este.	5a,MN	0	-	Unstable	Collapse	Voltage collapse
	5b,MN	20	PNOC-EDC	Stable	Stable	Slower V recovery
	5c,MN	25	PNOC-EDC	Stable	Stable	Faster V recovery
	5d,MS	25	PNOC-EDC	Stable	Stable	Stable
Fault at Laoag 115Kv	6a,MN	20	PNOC-EDC	Unstable	Collapse	Voltage collapse
	6b,MN	30	PNOC-EDC	Unstable	Collapse	Voltage collapse
	6c,MN	40	PNOC-EDC	Stable	Stable	Stable
	6d,MS	30	PNOC-EDC	Unstable	Collapse	Voltage collapse

	6e,MS	40	PNOC-EDC	Stable	Stable	Stable
Trip 1-700kW WT	7a	0	-	Stable	Stable	Stable
Energize 700kW	7b	0	-	Stable	Stable	Stable
B. PNOC-EDC 230-kV Connection Scheme						
Fault at Sn Este.	8a,MN	0	-	Unstable	Collapse	Voltage Collapse
	8b,MN	25	PNOC-EDC	Stable	Stable	Stable
	8c,MS	25	PNOC-EDC	Stable	Stable	Stable
Fault at Laoag 230kV	9a,MN	40	PNOC-EDC	Unstable	Collapse	Voltage collapse
	9b,MN	50	PNOC-EDC	Stable	Stable	Stable
Trip 1-700kW WT	7a	0	-	Stable	Stable	Stable
Energize 700kW	7b	0	-	Stable	Stable	Stable

7.3 SHORT-CIRCUIT ANALYSIS

The indicative short circuit levels of the selected 115-kV and 230-kV buses in the Ilocos and La Union provinces were computed. The summary of fault levels is shown in Tables 11.

Table 11. Indicative Substation Short-Circuit Level

Station	w/o PNOC-EDC	w/ PNOC-EDC	
	Existing	Fault Levels, in kA	
		115kV option	230kV option
Buang 230-kV	10.05	11	12
Sn Esteban 230-kV	2.17	3.5	4.5
Sn Esteban 115-kV	2.13	3.7	4.7
Bantay 115-kV	2.26	2.5	2.4
Currimaos 115-kV	1.56	1.8	1.97
Laoag 115-kV	1.63	1.9	2.05
Laoag 230-kV	-	-	1.95
PNOC-EDC 115-kV	-	1.6	1.9
PNOC-EDC 230-kV	-	-	1.7

Note that the resulting fault levels are way below the NPC standard fault-current interrupting capacity of 40-kA. This standard was set taking into consideration future generation additions in the system.

8. COST COMPARISON

8.1. DIRECT COST

The components required for each connection scheme are shown in Table 12. These consist of lines for generator connection, transmission reinforcements, and reactive compensation devices. Line cost were computed on a per kilometer basis. Reactive compensation devices and terminal equipment are on per unit cost basis. The exchange rate adopted is P50 to 1USD. It should be noted that the cost estimates made are for budgetary purposes only. The detailed cost estimates could only be done upon conducting a detailed facility study (i.e., after detailed surveys and engineering design are undertaken).

115-kV Connection Scheme. The direct cost for the 115-kV connection scheme is \$5.229 million dollars considering a STDC 1-795 MCM line structure. This is the cost of the associated line with from PNOG-EDC Wind Power Project in Burgos to Laoag. The cost details are shown in Table 12A.

The total project cost for this scheme would be \$18.691 million. This is so because on top of the direct cost, additional cost amounting to \$12.784 million is required for the new Bauang-Sn Esteban 230-kV Line and the Sn Esteban-Laoag 115-kV line, and \$0.678 for the compensation requirement. Note however that the switching devices used for the dynamic compensation scheme are not part of the cost estimate due to unavailability of data. The same is true for the reactive compensation cost for 230-kV connection scheme.

230-kV Connection Scheme. This scheme will have a total cost of about \$22.710 million dollars. The cost includes the cost of the 230-kV generator associated line, cost of 230-kV reinforcement line from Laoag to Sn Esteban and Sn Esteban to Bauang, and the cost transformation and compensation. This however excludes the step-up transformer at the generator side with 230-kV high-side voltage rating. The assumption is that the cost of the step-up transformers at PNOG-EDC is incorporated in the overall cost of the plant and is not included in the estimates. Refer to Table 12B for the cost details.

Table 12. Budgetary Cost Estimates
A. 115-kV CONNECTION SCHEME

FACILITIES	ESTIMATED COST, Million USD
1. Burgos – Laoag asso. 115-kV Line	5.229
• STDC 1-795 MCM, 40 kms.	4.712
• 115-kV PCBs + ACC., 4 sets	0.517
2. Capacitor Compensation	0.678
• 5-5 MVar 115-kV bank for Steady-State	0.261
• 8-5 MVar 115-kV bank for Dynamic	0.417
3. Bauang-Sn Esteban 230-kV Line	2.583
• 2 nd ckt stringing, 1-795 MCM, 90 kms	1.998
• 230-kV PCBs + ACC., 4 sets	0.585
4. Laoag-Sn Esteban 115-kV Line	10.201
• STSC, 1-795 MCM, 120 kms	9.684
• 115-kV PCBs + ACC., 4 sets	0.517
TOTAL	18.691

B. 230-kV CONNECTION SCHEME

FACILITIES	ESTIMATED COST, Million USD
1. Burgos – Laoag asso. 230-kV Line	5.977
• STDC 1-795 MCM, 40 kms.	5.392
• 230-kV PCBs + ACC., 4 sets	0.585
2. Capacitor Compensation	0.783
• 5-5 MVar 115-kV bank for Steady-State	0.261
• 10-5 MVar 115-kV bank for Dynamic	0.522
3. Bauang-Sn Esteban 230-kV Line	2.583
• 2 nd ckt stringing, 1-795 MCM, 90 kms	1.998
• 230-kV PCBs + ACC., 4 sets	0.585
4. Laoag-Sn Esteban 230-kV Line	13.367
• STSC, 1-795 MCM, 120 kms	11.472
• 230-kV PCBs + ACC., 5 sets	0.732
• 1-50 MVA 230/115 KV Transformer	1.034
• 115-kV PCB + ACC, 1 set	0.129
TOTAL	22.710

8.2. ECONOMIC COMPARISON

By comparing the total costs of each connection alternative, we can readily see which alternative requires the least capital investment. To determine the least-cost alternative, the capitalized cost of operation and maintenance and the benefit on reduced system losses over the economic life of the facilities are included in the comparison. The annual operation and maintenance (O&M) cost was assumed to be 5% of direct cost of the transmission facility. The net present value was based on a 12% discount rate over an economic life of 30 years.

The comparative system losses for each connection schemes were generated using the same loadflow models. There is a reduction in system loss of about 1MW for a 230-kV connection in comparison to the 115-kV connection scheme. With a loss factor of 15% and the cost of energy valued at P3.00/kWh, the annual cost reduction due to lower system loss is about P31.95 million (\$0.71million).

An overall economic comparison indicate that the 230-kV connection alternative is prohibitively expensive for the wind farm generation project of NPC. The technical advantages derived including the reduction in line losses from this connection scheme is not sufficient to offset its high cost.

Table 13. Comparative Costs of Alternatives
Cost in Net Present Value, USD million

CONNECTION SCHEME	PROJECT COST	O&M COST	LINE LOSS COST	TOTAL COST
115 KV CONNECTION	18.691	7.53	1.27	27.491
230 KV CONNECTION	22.710	9.15	0.64	32.500

Note: Line loss for 115kV is 2MW/yr or 2.63 GWH/yr or an annual loss of USD 0.1578. For 230-kV line loss is reduced to half.

9. SUMMARY AND CONCLUSIONS

From the foregoing discussions of the results of the study, the following could be concluded:

- The 42-MWe Wind Power Project of PNOC-EDC for 2002 will be able to satisfactorily operate within the Luzon Grid via 115-kV connection to NPC Laoag Substation, considering the long-term transmission

expansion plans of NPC for 2000-2005. However, to meet the reliability standards of NPC, modification of this plan may be required as identified in the study.

- The use of inductive generators in contrast with the more conventional synchronous machines will require a special dynamic reactive power compensation scheme for the project to ensure its stable operation. Initially, the study has determined the need for 40 MVar of dynamic reactive compensation for this project in addition to the 25 MVar of fixed shunt compensation. More detailed studies should be conducted regarding the optimum design of the reactive compensation to consider other factors such as switching transients and voltage flickers upon the final selection of the wind turbine equipment.
- The 115-kV connection is a more economical alternative considering present cost although the 230-kV could provide greater flexibility for further developments in the future. For this reason, the use of 230-kV design on the planned 115-kV transmission line additions may be economically justified for PNOC-EDC to facilitate future expansions as well as future voltage uprating of NPC transmission line in the area.

Overall, the result of the study indicate that the proposed project is technically viable considering the expansion plans of NPC and the necessary system improvements that were identified. However, the result of this study does not in any way bind NPC to any commitment or obligations with PNOC-EDC other than what was stipulated in the Letter of Agreement for the performance of the System Impact Study.

The results of the study were obtained through power system simulations using the best available information from the 1999 Power Development Program (PDP) of NPC and assumptions used in economic evaluations for transmission planning.

Changes or updates in the PDP may affect some of the results and conclusions in this System Impact Study. PNOC-EDC is encouraged to enter into a Transmission Service Agreement with NPC to secure the required transmission service against changes in NPC's expansion plans.

Lastly, the accuracy of the budgetary project cost estimates on connection or reinforcement facilities may vary among suppliers and contractors as well as the procurement procedures and project arrangements being adopted.

