

Analysis Of Six-Phase System For Transmission Line

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Abstract - Electrical system engineer forecast possibility introduced the transmission line the six-phase system to change system that the present is the double-circuit three-phase system. This is because application rate caused electricity consumer demands more urgent and increase. Revenue from past research, obtain the transmission line six-phase system has several advantages as transmission line voltage higher compared line that the present. In case normal, the transmission line six phase system get enhance the capability delivery as many as 73% over line that the present, impact reduction corona and decline magnetic field also succeed bring good to the environment. Small development system use but afford enhance the capability line space basis and transmission line features, this study is over converging to analysis the design for transformer six-phase system. Comparison by system count per-unit use MATLAB and PSCAD/ EMTDC simulation implemented for both system. Analysis of data carried out for parameters as value phase difference, voltage, current and power in transmission line. Apart from that assessment choose the best transformer design for six-phase system also implemented. From the analysis data performed found line system six phase have successfully produced ascendant as many as 73% in the division transmission line over system double three-phase circuit. Apart from obtain that the best connection six phase system to acquire stated ascendant is delta-wye delta-inverted wye connection and diametrical connection.

Index Terms – PSCAD, Six-phase, three-phase, transmission line, overhead line

I. INTRODUCTION

Mostly, high transmission system which exceeded 230kV uses three phase ac for power transfer. Three-phase ac been selected because of it's more efficient to generate power. Power generation with phase angle less than 120° will not cause ascendant output [2]. Power transmission system concept exceed three phase is new discovery. It was introduced first time by the electric researcher committee in year 1973. This idea have many advantages and need for continued research.

Three phase system have 120° phase difference and the line voltage is $\sqrt{3}$ voltage phase. While the six phase system also have 60° phase difference and the line voltage equivalent on it phase voltage. Six-phase system able to increase power as many as 73% transmission delivery, low insulator needed, produce more stable system, reduction corona and magnetic field impact and enhancement space capability overhead line which has propelled engineer to carry out research on six phase system.

This study been perform to prove characteristic of six phase system, making system analysis on six phase control transmission line through simulation PSCAD/EMTDC and choose the best converter connection for six phase system. By refer to the objective wish to be achieved, scope of study that prescribed is implement count use the software MATLAB, doing simulation and six phase system analysis and choosing design for best converter six phase system.

II. BACKGROUND STUDY

Beginning of the year 1973, high phase transmission concept been introduced [2]. Further, in the year 1976, Allegheny Power Service Corporation (APS) collaboration with West Virginia University had conducted research analytically design on high phase delivery. This research received fund from National Science Foundation. This effort been seen as a successfully of an alternative to high phase transmission system. Nevertheless, this project finally found abandoned and APS endeavoured to carry out others research in the future.

Then in the year 1982, Department of Energy (DOE), United States and New York State Energy Research and Development Authority (NYSERDA) had conducted that study of corona impact and magnetic field for line high transmission phase. To implement this study, high phase transmission line to Test System been build in NYSERDA MALTA, New York.[2].

At the end of September 1983, final result from the study showed the six phase transmission could supply power capacity similar as three phase system with the reduction overhead line space to magnetic field and audio noise, reduce delivery structure and lower down the overall cost. Further, in early 1990, Empire State Electric Energy Research

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Corporation with New York State Electric & Gas (NYSEG) collaboration has implemented demonstration project of High Phase Transmission for research purpose and operations six phase system. This project have short transmission line from Goudey until Oakdale with configuration from double circuit three phase 115kV system to 93kV six phase system with the distance 1.5 miles and being resume to the 115kV system through two three phase converter 161kV / 115kV with a connection shape Delta/Y(Earth) and connection Delta/Reverse Y(Earth)[4].

$$V_{DN} = V_{AN} \angle -180^\circ$$

Six phase system with balance have 60° phase difference in such Fig. 1. This figure shows phase to phase voltage relation and phase to neutral voltage to six phase system can be acquired. For six phase system, phase to phase voltage is equal to phase to neutral voltage. The types of voltages relationship for six phase system can be divided as follow:

- i. Phase-to-phase voltage, V_L
: $V_{AB}, V_{BC}, V_{CD}, V_{DE}, V_{EF}, V_{FA}$
- ii. Phase-to-neutral voltage, $V_{L-Group}$
: $V_{AC}, V_{BD}, V_{CE}, V_{DF}, V_{EA}, V_{FB}$,
- iii. Phase-to-crossphase voltage, $V_{L-Crossphase}$
: V_{AD}, V_{BE}, V_{CF}

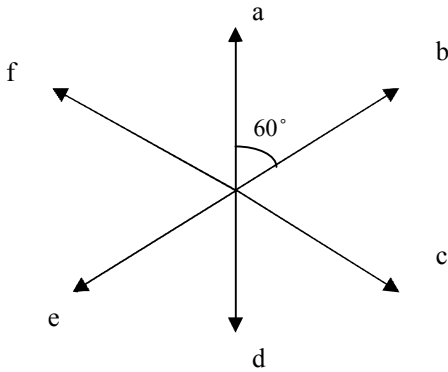


Fig. 1 Phasors of six-phase system

As generally relation phase to neutral voltage, are as follows with presumption that V_{AN} as references.

$$\begin{aligned} V_{AN} &= V_{AN} \angle 0^\circ \\ V_{BN} &= V_{AN} \angle -60^\circ \\ V_{CN} &= V_{AN} \angle -120^\circ \\ V_{DN} &= V_{AN} \angle -180^\circ \\ V_{EN} &= V_{AN} \angle -240^\circ \\ V_{FN} &= V_{AN} \angle -300^\circ @ +60^\circ \end{aligned}$$

Phase-to-phase voltage is similar with voltage line and his association with phase to neutral voltage are as follows: (Assuming the $V_{AN} = V_{BN} = V_{CN} = V_{DN} = V_{EN} = V_{FN}$)

$$\begin{aligned} V_{AB} &= V_{AN} \angle 0^\circ - V_{BN} \angle -60^\circ \\ &= V_p (1 \angle 0^\circ - 1 \angle -60^\circ) \\ &= V_p (1 + j0 - (0.5 - j0.866)) \\ &= V_p (0.5 + j0.866) \\ &= V_p \angle 60^\circ \end{aligned}$$

III. METHODOLOGY

Two software been used in this study are PSCAD/EMTDC and MATLAB software. PSCAD/EMTDC used for six phase system simulation because of it simulate professional power system device for analysis. PSCAD have consumer interface with graphic "GUI- Graphical user Interface" which found easy and attractive with more flexible. PSCAD also allow user to build schematic circuit, simulate and analyze result from basic circuit to circuit complex.

While MATLAB's software been use to accelerate and check theoretical measurement. Study been carried out on three samples, Test System I, Test System II and Test System III. Parameters for Test System III acquired from Tenaga Nasional Berhad (TNB), Johor Bahru Selatan, Malaysia which is Gelang Patah-Tanjung Kupang Johor's line. Each Test System contains six phase system analyze through mathematics and simulation. There are two types of single-phase transformers can be used to build a three to six phase conversion transformer.

First, six identical single-phase two-winding transformers may be connected to form three-to-six-phase bank. Secondly, three identical single-phase three-winding transformers may be connected together to form three-to-six-phase bank. Voltage and current magnitude depends on the windings connection

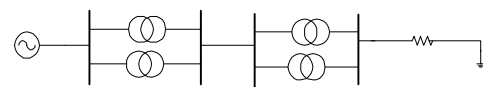
used on the primary and the secondary sides of the three-to-six-phase conversion transformer. The primary or secondary side of the three-to-six-phase conversion transformer may be connected by using any combinations of either Wye (Y) or Delta (Δ) connections. Six phase system has five connection form of transformer instrument which are wye-wye wye-inverted wye (Y-Y Y-inverted Y) connection, delta-wye delta-inverted wye (Δ -Y Δ -Inverted Y) connection, diametrical connection, two delta connection and two star connection. Table I show six phase transformer connections with schematic diagram. Table II show parameters for Test System I, Test System II and Test System III. Fig. 2 show one-line diagram for six-phase system.

TABLE I SIX-PHASE TRANSFORMER CONNECTIONS WITH SCHEMATIC DIAGRAM

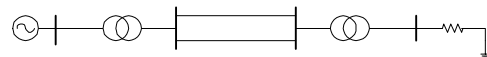
Types of Connection	Schematic Diagram
Wye-Wye Wye-Inverted Y	
Delta-Wye Delta-Inverted Y	
Diametrical	
Double Delta	
Double Wye	

TABLE II PARAMETERS OF TEST SYSTEM I, TEST SYSTEM II AND TEST SYSTEM III

Test System	I	II	III
Generator			
i. The Supply Voltage	138kVA	115kV	22kV
ii. MVA Base	600MVA	150MV A	60MVA
iii. Frequency	50Hz	50Hz	50Hz
Transformer			
i. The primary voltage	138kV	115kV	22kV
ii. The secondary voltage	138kV	161kV	132kV
iii. MVA Base	600MVA	150MV A	60MVA
Transmission Line			
i. The impedance	0.3108+ j0.544 Ω	0.1554+ j0.272 Ω	0.775+ j1.3642 Ω
Load			
i. The impedance	1000 Ω	1000 Ω	1000 Ω



(a) The six-phase transmission line with used two transformers



(b) The six-phase transmission line with used one transformer

Fig. 2 One-line diagram of six-phase transmission line

IV. RESULTS AND DISCUSSION

For Test System 1, analysis for each transformer connection been implemented and found six phase system have phase difference of 60° , phase current of $79.305 \angle -1.3476^\circ$ A and the voltage phase same as the line voltage which is 138kV to transmission line division. While the value on the supply part and load is equivalent. This show transmission line division

only transfer from three phase system to six phase system because of changing in the form transformer connection which is used.

From five connection form, stated only three connection those validate the phase difference of 60° , and the voltage phase is same as voltage line which is delta- Δ -inverted wye connection, wye- Δ -inverted wye connection and diametrical connection. Further analysis involves three stated connection. Table III show the result of theoretical and Matlab Simulation for Test System I, while Fig. 3 and 4 shows the schematic circuit for six phase system for Test System I to concerning connections.

TABLE III THE RESULT OF THEORETICAL AND MATLAB SIMULATION FOR TEST SYSTEM I

Connections	Delta-Wye		Wye-Wye	
	Delta-Inverted Wye		Wye-Inverted Wye	
Value	Calculation	MATLAB	Calculation	MATLAB
Generator Part				
I_{phase} (A)	79.305	79.2779	79.2548	79.2779
V_{phase} (kV)	79.67	79.677	79.67	79.677
Angle (Radian)	1.3476	1.6230	1.3476	1.6230
Apparent Power (MVA)	18.94	18.950	18.94	18.950
Real Power (MWatt)	18.94	18.949	18.94	18.949
Reactive Power (MVar)	0.1196	0.11969	0.1196	0.11969
Transmission Line				
V_{phase} (kV)	138	138	79.67	79.677
V_{line} (kV)	138	138	79.67	79.677
Phasor Angle ($^\circ$)	+/-60	-	+/-60	-
Load				
I_{phase} (A)	79.2548	79.2779	79.2548	79.2779
V_{phase} (kV)	79.2548	79.278	79.2548	79.278
Angle (Radian)	0	0	0	0
Apparent Power (MVA)	18.84	18.855	18.84	18.855
Real Power (MWatt)	18.84	18.855	18.84	18.855
Reactive Power (MVar)	0	0	0	0

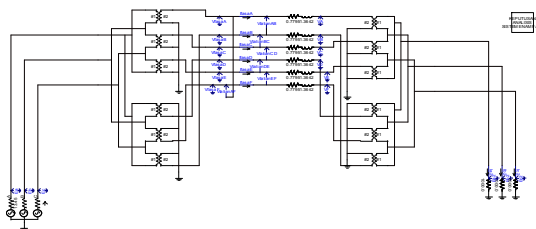


Fig. 3 The schematic circuit six-phase system for delta-wye, delta- inverted wye connection Test System I

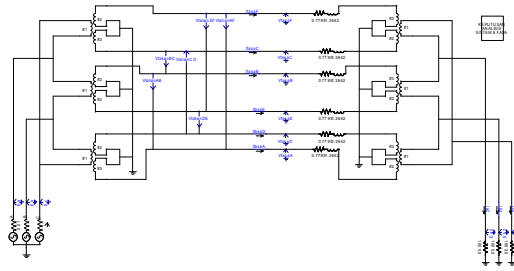


Fig. 4 The schematic circuit six-phase system for diametrical connection Test System I.

Table IV shows about Test System I on all three connections achieve 60° phase difference on transmission line division. While, the phase voltage equal to the voltage line. For delta-wye delta-inverted wye connection and diametrical connection experience voltage increase to transmission division from 79kV to 137.5kV. Meanwhile, wye-wye wye-inverted wye not suffer voltage increase on the transmission line division which is permanent to 79.02kV. Voltage increase for transmission line influence by delta to wye connection. When voltage increase and equivalent current, then, by using equation $P = V_{\text{phase}} I_{\text{phase}} \cos \theta$ acquired 65.71MWatt and 65.42MWatt to delta-wye delta-inverted wye connection and diametrical connection.

While for wye-wye wye-inverted wye only have 37.80MWatt. Voltage increase had stepped up six phase power and obtainable delta-wye delta-inverted wye acquired 70.74%, diametrical connection acquired 70.76 % and wye-wye wye-inverted wye form only -1.85%. Then both six phase connection system approaching 73% and it is an increase over three phase system.

Equivalent analysis also done between Test System II and Test System III. Table V show the result of theoretical and Matlab Simulation for Test System II.

TABLE IV THE RESULT OF SIX-PHASE SYSTEM FOR TEST SYSTEM I WITH PSCAD/EMTDC SIMULATION.

Value	Delta-wye, delta-inverted wye	wye-wye wye-inverted wye	Diametrical
The Generator Part			
I_{phase} (A)	79.23	78.91	79.24
V_{phase} (kV)	79.27	79.28	79.28
The apparent power (MVA)	18.84	18.77	18.85
The real power (MWatt)	18.83	18.68	18.84
The reactive power (MVar)	0.5962	1.774	0.5367
The Transmission Line			
Phasor angle ($^\circ$)	+/-59.61	+/-59.81	+/-60.33
V_{phase} (kV)	137.5	79.02	137.6
V_{line} (kV)	137.6	79.42	137.6
$P_{\text{six-phase}}$ (MWatt)	65.41	37.60	65.42
Percentage of power increment (%)	70.74	-1.85	70.76

TABLE V THE RESULT OF THEORETICAL AND MATLAB SIMULATION FOR TEST SYSTEM II

Connections	Delta-Wye		Wye-Wye	
	Delta-Inverted Wye		Wye-Inverted Wye	
Value	Calculation	MATLAB	Calculation	MATLAB
Generator Part				
I_{phase} (A)	66.45	66.4590	66.45	66.4590
V_{phase} (kV)	66.395	66.397	66.395	66.397
Apparent Power (MVA)	13.236	13.039	13.236	13.039
Real Power (MWatt)	13.236	13.031	13.236	13.031

Reactive Power (MVar)	0.543	0.4595	0.543	0.4595
The Transmission Line				
V _{phase} (kV)	161	161	92.95	92.956
V _{line} (kV)	161	161	92.95	92.956
P _{Enam fasa} (MWatt)	64.14	63.109	37.03	36.486
The Load				
I _{phase} (A)	66.45	66.459	66.45	66.45
V _{phase} (kV)	66.45	65.459	66.45	66.45
Apparent Power (MVA)	13.247	12.855	13.247	13.247
Real Power (MWatt)	13.247	12.855	13.247	13.247

From Table VI show for Test System II connection all three phase difference 60° achieve on the transmission line division. While the phase voltage are the same with the line voltage. To delta-wye delta-inverted wye connection and diametrical connection experience voltage increase to transmission division from 65kV to 159kV. Meanwhile, wye-wye wye-inverted wye connection also experienced voltage increase to 92kV. Voltage increase for transmission line influence by delta to wye connection and turns transformer ratio which are used. Then acquired 62.96MWatt and 62.72MWatt to delta-wye delta-inverted wye connection and diametrical connection. While for wye-wye wye-inverted wye only 36.28MWatt. Voltage increase had stepped up power six phase system and obtainable delta-wye delta-inverted wye acquired 72.40%, diametrical connection form acquired 71.74% and wye-wye wye-inverted wye form only -0.657%. Therefore,

found that both six phase connection system achieve 73% and increase more compared three phase system.

Third sample, Test System III which is sample parameter obtainable from Tenaga Nasional Berhad, Malaysia. Gelang Patah's line, Johore to Tanjung Kupang, Johore. It been selected for analyzed because of it use the two circuit three phase system. This line bring 132kV with distance 16.19 km or 32.38cct km. Converter been used form Star-Star (Y-Y). Some of the data in this in line been added to suit with software requirement which are used. Policy been chosen is 60MVA, 22kV and $R=13.45 \Omega$ to generator. Converter which are used is Y-Y, with this policy 60MVA, 22kV / 132kV and $X=0.1$ pu. Transmission line distance is 16.19km and static is 1000 Ω . Table VII show the theoretical result of Matlab Simulation for Test System III.

TABLE VI THE RESULTS OF SIX-PHASE SYSTEM FOR TEST SYSTEM II USING PSCAD/EMTD SIMULATION

Value	Delta-wye, delta-inverted wye	wye-wye wye-inverted wye	Diametrical
The Generator Part			
I _{phase} (A)	65.71	65.55	65.74
V _{phase} (kV)	65.71	65.74	65.74
The apparent power (MVA)	12.96	12.93	12.96
The real power (MWatt)	12.95	12.89	12.96
The reactive power (MVar)	0.3226	0.963	0.09437
The Transmission Line			
Phasor angle ($^\circ$)	+/-58.72	+/-60	+/-60.33
V _{phase} (kV)	159.7	92.2	159.20
V _{line} (kV)	159.7	92.24	159.0
P _{six-phase} (MWatt)	62.96	36.28	62.72
Percentage of power increment (%)	72.40	-0.657	71.74

From Table VIII show all three achieve phase difference 60° connection on the part transmission line to Test System III.

While the phase voltage are same with the line voltage. For delta-wye delta-inverted wye connection and diametrical connection experience voltage increase to transmission division from 12.66.kV to 131kV. Meanwhile, wye-wye wye-inverted wye connection also experienced voltage increase to 75kV. Then, acquired 10.01Mwatt and 9.811Mwatt to delta-wye delta-inverted wye connection and diametrical connection. While for wye-wye wye-inverted wye only 5.746Mwatt. Voltage increase had stepped up six phase power and obtainable form delta-wye, delta-inverted wye acquired

76.77%, diametrical connection acquired 73.71% and form wye-wye wye-inverted only -1.442%. Then found that both six phase connection system achieve 73% and increase more compared three phase system. From all Test System's systems, result of simulation circuit obtain same with calculation has been shown. This study has shown, the six phase system can achieve ascendant as 73% which stated previously. Transmission connection which successfully archive the increment delta-wye delta-inverted wye connection and diametrical connection which is exceed 73%.

TABLE VIII THE RESULTS OF SIX-PHASE SYSTEM FOR TEST SYSTEM III USING PSCAD/EMTD SIMULATION

Value	Delta-wye, delta-inverted wye	wye-wye wye-inverted wye	Diametrical
The Generator Part			
I _{phase} (A)	12.66	12.66	12.53
V _{phase} (kV)	12.66	12.66	12.53
Angle (Radian)	0.003598	0.01079	0.003194
The apparent power (MVA)	0.4807	0.4806	0.4712
The real power (MWatt)	0.4806	0.4806	0.4712
The reactive power (MVar)	0.001729	0.005187	0.001505
Transmission Line			
Phasor angle (°)	+/-59.61	+/-59.07	+/-59.43
V _{phase} (kV)	131.8	75.65	130.5
V _{line} (kV)	131.8	75.65	130.5
P _{six-phase} (MWatt)	10.01	5.746	9.811
Percentage of power increment (%)	76.77	1.442	73.71

Apart from that, this study has proved that PSCAD/EMTDC software available for power analyzes on the division generation, transmission line and load. This proof also proven that apparent power, active power and reactive power were in the six phase system which also obtainable from it simulation. This is because power generation and power distribution use the three phase system. While on the transmission line division, calculation from simulation data need to be carried out to get power in transmission line. Only difference interphase, current and voltage can be acquired from simulation in the division transmission line.

V. CONCLUSION

After power transmission been analyzed by using the six phase system, it can be concluded that, the six phase system is one an alternative to replace double three phase circuit. From literature study those stated, proves that transmission line with six phase system has several advantages as high phase transmission line. Six phase transmission line system get

enhance the capability delivery as many 73% over with double-circuit three-phase system. Number phase increase will cause reduction

gradient conductor surface. For reduction of corona effect, audio noise, television and radio interference and magnetic field giving good impact to the environmental. By implement small development structure on the system use, it found affordable to enhance the capability overhead line space on it system advantages.

With supply to the power transmission concept, simulation for double circuit three phase model system and six phase system used the PSCAD/EMTDC software were implemented. PSCAD/EMTDC is a software package to cope deep analysis to apply simulation for system power circuit. From it simulation, power transmission efficiency can be determine. Outcome from the result shows in the wave graph form, metre digit or analogue meter. Other than that, retrenchment in terms of cost also obtainable because of this software can give

accurate estimate respond based on parameters are given to analyzed circuit.

Although as theoretically, the six phase system giving a lot of advantages, results from it implementing towards power system practically must given attention. The purpose to know either the six phase system really given good or instead. Some of the factors that influence system during real operation must be taken into account. For example, converter three phase transformer to six phase result of one device that most critical in design system six phase. After all factors been addressed, a mathematical model six phase system can be further shaped to enable analyse of load flow committed against six phase system.

This study act as pioneer to design the six phase system by using the PSCAD/EMTDC software. As preparation to face globalization era, made the system very important to use multiple phase as an alternative to three phase system. As a developing country, demand for power supply will increase parallel with the development exponential in the industrial field country. Hence that, wish this project become a stepping stone to understanding and design of four phase system. It become difficult process and really need deep knowledge relating with the system characteristic which need to design.

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