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Analysis and Comparative Study of Six Phase Transmission System

G.Chandra Sekhar¹, I.Satish Kumar²

Professor, Dept. of EEE, GMR Institute of Technology, Rajam, Andhra Pradesh, India

Professor, Dept. of EEE, GMR Institute of Technology, Rajam, Andhra Pradesh, India

ABSTRACT: Six Phase Transmission System has the capacity to increase the transmission capacity by 1.732 times the existing Three Phase System. It is possible to convert existing Three Phase Double circuit transmission line into compact Six Phase transmission line within the existing Right-of-way. Forecasting the demand and supply of Electrical energy gives the alternative solution is Six Phase Transmission system in addition to its several advantages like reduced phase voltage, less corona, declined magnetic field etc. This paper presents the study and analysis of design of transformer for 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 choosing 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-Star delta-inverted Star connection and diametrical connection.

KEYWORDS: Multi Phase, Six-phase, Six phase Transmission, simulation

I. INTRODUCTION

High Phase Transmission system[1] which exceeds 230kV uses Three Phase A.C for Bulk power transfer. Three-phase A.C has 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 with increasing number of phases is new discovery. It was introduced first time by the electric researcher committee in year 1973. This idea have many advantages and leads to continued research for decades[3].

The Phase displacement in Three phase system is 120° and the line voltage is $\sqrt{3}$ times the Phase voltage. While the six phase system has 60° phase difference and the line voltage is equal to the 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[4].

This study been perform to prove characteristic of six phase system, making system analysis on six phase transmission line through simulation PSCAD/EMTDC[5] for three Test systems and choose the best converter connection for six phase system.

II. OVER VIEW OF SIX PHASE SYSTEM

In the year 1973, high phase order transmission concept had been introduced [2]. Further, in the year 1976, Allegheny Power Service Corporation (APS) conducted the research on Six Phase Transmission system in collaboration with West Virginia University. This research received fund from National Science Foundation. This effort laid down the

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stone to start the research in the Multiphase Transmission in world wide.

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 high phase transmission line. To implement this study, Multi phase transmission line Test System been built in NYSERDA MALTA, New York.[6].

At the end of September 1983, final result from the study showed that the power transmission capacity in six phase system increases by 1.732 times that of three phase system with the reduction overhead line space, magnetic field and audio noise, which leads reduce in delivery structure and lower down the overall cost. Further, in early 1990, Empire State Electric Energy Research Corporation with New York State Electric & Gas (NYSEG) collaboration has implemented demonstration project of High Phase Transmission for research purpose and operations on six phase system[6]. Under this project the existing 115kV Three Phase Double circuit transmission line from Goudey to Oakdale is upgraded to 93kV six phase system with the distance 1.5 miles and being step up 115kV system through two three phase converter 161kV / 115kV with a connection shape Delta/Y(Earth) and connection Delta/Reverse Y(Earth).

Six Phase Transmission system is the combination of two Three phase systems ABC and A'B'C'. In Three Phase system ABC all the three phase are displaced by 120° and in another Three Phase system A'B'C' all the three phase are displaced by 120° in such a way that the phase A and A', phase B and B', Phase C and C' are in out of phase. This results the phase angle between each phase in a compact Six Phase Transmission System is 60° . This will make easier to convert the existing Double three phase Transmission line into a compact Six Phase Transmission line.

Six Phase with balance system have 60° phase difference is shown in Fig.1. This figure shows phase to phase voltage relation and phase to neutral voltage of six phase system can be derived.

Let Phase a be taken as reference. The six phase voltages are as follows.

$$V_{AN} = V_{AN} \angle 0^\circ \quad V_{BN} = V_{AN} \angle -60^\circ \quad V_{CN} = V_{AN} \angle -120^\circ \quad V_{DN} = V_{AN} \angle -180^\circ \quad V_{EN} = V_{AN} \angle -240^\circ \quad V_{FN} = V_{AN} \angle -300^\circ$$

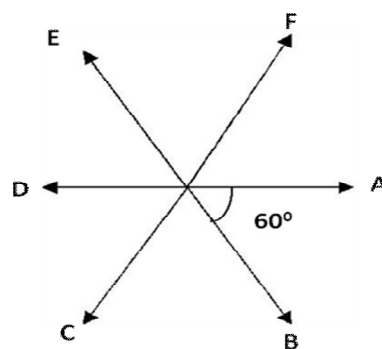


Fig.1 Phasors of six Phase system

For Six phase system the phase to phase voltage is equal to phase to neutral voltage. The types of voltage relations ships for six phase system can be divided as follows.

Phase-to-phase voltage, V_L : $V_{AB}, V_{BC}, V_{CD}, V_{DE}, V_{EF}, V_{FA}$

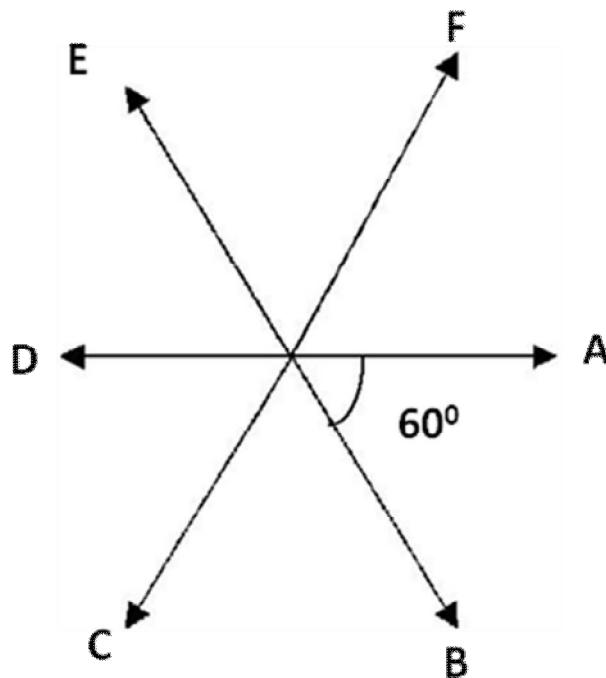
Phase-to-neutral voltage, $V_{L-Group}$: $V_{AC}, V_{BD}, V_{CE}, V_{DF}, V_{EA}, V_{FB},$

Phase-to-crossphase voltage, $V_{L-Crossphase}$: V_{AD}, V_{BE}, V_{CF}

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III. METHODOLOGY

The softwares used in this study are PSCAD/EMTDC and MATLAB. The former one used for six phase system simulation because of its interfacing application with graphic “GUI- Graphical user Interface” which found easy and attractive with more flexible. It also allows user to build schematic circuit, simulate and analyze result from basic circuit to circuit complex.

The later one used to accelerate and check theoretical measurement. Study has been carried out on three samples, Test System I, Test System II and Test System III. Parameters for Test System III are acquired from Tenaga Nasional Berhad (TNB), Johor Bahru Selatan, Malaysia which is Gelang Patah-Tanjung Kupang Johor's line[7,8]. 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.

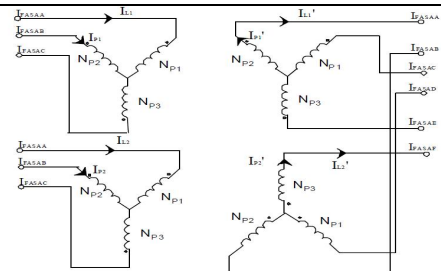
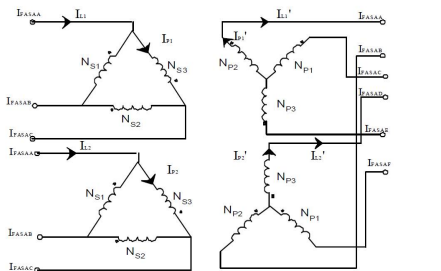
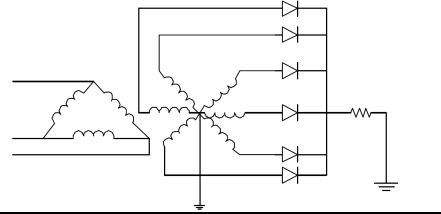
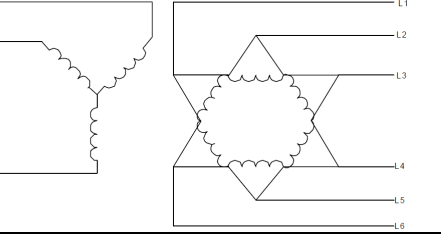
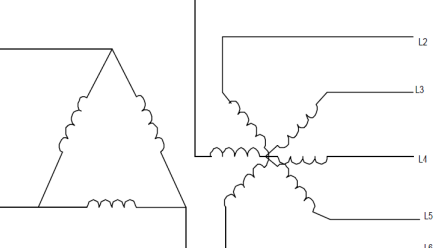
First, six identical Single-Phase Two-Winding transformers are connected to form Three-to-Six-Phase bank. Secondly, three identical Single-Phase Three-Winding transformers are connected together to form Three-to-Six-Phase bank. Voltage and current magnitude depends on the windings connection used on the primary and the secondary sides of the Three-to- Six-Phase conversion transformer[9]. The primary or secondary side of the Three-to-Six-Phase conversion transformer may be connected by using any combinations of either Star (Y) or Delta (Δ) connections. Six Phase system has five connection form of transformer instrument[10,11] which are Star-Star Star-inverted Star (Y-Y / Y-inverted Y) connection, delta-Star delta-inverted Star (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.

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Table I Six-Phase Transformer Connections With Schematic Diagram

Types of Connection	Schematic Diagram
WyeWye WyeInverted Y	
DeltaWye DeltaInverted Y	
Diametrical	
Double Delta	
Double Wye	

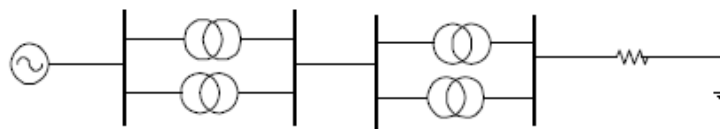
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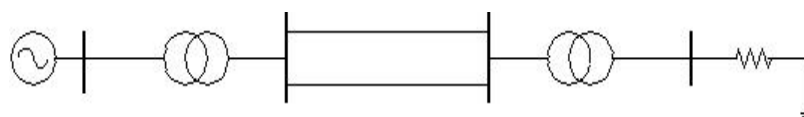
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TABLE II Parameters Of Test System I, Test System II And Test System III

Test System	I	II	III
Generator			
Supply voltage	138kV	115kV	22kV
MVA Base	600MVA	150MVA	60MVA
Frequency	50Hz	50Hz	50Hz
Transformer			
Primary Voltage	138kV	115kV	22kV
Secondary Voltage	138kV	161kV	132kV
MVA Base	600MVA	150MVA	60MVA
Transmission Line			
Impedance	$0.3108 + j 0.544 \Omega$	$0.1554 + j 0.272 \Omega$	$0.775 + j 1.3642 \Omega$
Load			
Impedance	1000Ω	1000Ω	1000Ω



(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

III. 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 79.204A 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 shows transmission line division only transfer from Three Phase System to Six Phase System because of changing the transformer connection which is used.

From five connection form, stated only three connection those validate the phase difference of 60° , and the Phase Voltage is same as Line Voltage which is delta-Star delta-inverted Star connection, Star-Star Star-inverted Star 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

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System for Test System I to concerning connections.

Table III The Result Of Theoretical And MATLAB Simulation For Test System I

Connections	Delta-Star	Delta-Inverted star	Star-Star	Star-Inverted Star
Value	Calculation	MATLAB	Calculation	MATLAB
Generator Part				
$I_{\text{Phase}} \text{ (A)}$	79.204	79.274	79.258	79.279
$V_{\text{Phase}} \text{ (kV)}$	79.62	79.677	79.65	79.678
Angle (Radian)	1.3446	1.613	1.3476	1.613
Apparent Power (MVA)	18.91	18.94	18.91	18.94
Real Power(MW)	18.91	18.94	18.91	18.94
Reactive Power (MVar)	0.1194	0.11964	0.1194	0.11964
Transmission line				
$V_{\text{Phase}} \text{ (kV)}$	138	138	79.62	79.64
$V_{\text{Line}} \text{ (kV)}$	138	138	79.62	79.64
Phase Angle (Degrees)	+/-60	-	+/-60	-
Load				
$I_{\text{Phase}} \text{ (A)}$	79.23	79.2	79.258	79.279
$V_{\text{Phase}} \text{ (kV)}$	79.248	79.272	79.256	79.271
Angle (Radian)	0	0	0	0
Apparent Power (MVA)	18.82	18.852	18.82	18.852
Real Power(MW)	18.82	18.852	18.82	18.852
Reactive Power (MVar)	0	0	0	0

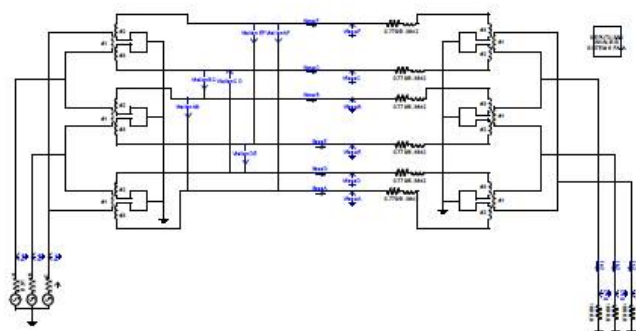


Fig. 3 The schematic circuit six-phase system for delta-Star, delta- inverted Star connection Test System I

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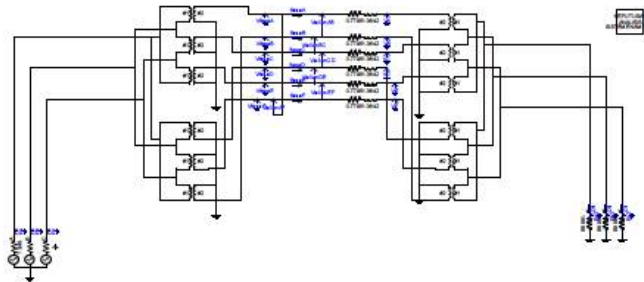


Fig. 4 The schematic circuit six-phase system for diametrical connection Test System I.

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 Line voltage. For delta-Star delta-inverted Star connection and diametrical connection experience voltage increase to transmission division from 79kV to 137.5kV. Meanwhile, Star-Star Star-inverted Star not suffer voltage increase on the transmission line division which is permanent to 79.02kV. Voltage increase for transmission line influence by delta to Star connection. When there is increase in voltage and current, then, by using equation $P = V_{\text{phase}} I_{\text{phase}} \cos \theta$ acquired 65.76Mwatt and 65.46Mwatt to delta-Star delta-inverted Star connection and diametrical connection. While for Star-Star Star-inverted Star only have 37.62MW. Voltage increase had stepped up Six Phase power and obtainable delta-Star delta-inverted Star acquired 70.76%, diametrical connection acquired 70.76 % and Star-Star Star-inverted Star form only -1.81%. 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.

Connections /Value	Delta-Star Inverted star	Star-Star Inverted Star	Diametrical
Generator Part			
I_{Phase} (A)	79.34	78.96	79.34
V_{Phase} (kV)	79.28	79.28	79.28
Apparent Power (MVA)	18.81	18.72	18.75
Real Power(MW)	18.83	18.68	18.84
Reactive Power (MVar)	0.5964	1.724	0.5347
Transmission Line			
Phase Angle (Degrees)	+/-59.63	+/-59.83	+/-60.30
V_{Phase} (kV)	137.5	79.03	137.8
V_{Line} (kV)	137.8	79.45	137.8
$P_{\text{Six-Phase}}$ (MW)	65.76	37.62	65.46
% of Power Increment(%)	70.76	-1.81	70.76

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TABLE V The Result Of Theoretical And Matlab Simulation For Test System Ii

Connections	Delta-Star Inverted star	Delta- Inverted Star	Star-Star Inverted Star	Star- Inverted Star
Value	Calculation	MATLAB	Calculation	MATLAB
Generator Part				
I_{Phase} (A)	66.44	66.452	66.44	66.46
V_{Phase} (kV)	66.34	66.38	66.38	66.38
Apparent Power (MVA)	13.234	13.01	13.24	13.03
Real Power(MW)	13.24	13.02	13.24	13.03
Reactive Power (MVar)	0.544	0.455	0.538	0.455
Transmission line				
V_{Phase} (kV)	161	161	92.98	92.96
V_{Line} (kV)	161	161	92.98	92.96
Phase Angle (Degrees)	64.16	63.11	37.04	36.49
Load				
I_{Phase} (A)	66.46	66.46	66.46	66.46
V_{Phase} (kV)	66.46	65.46	66.46	66.46
Apparent Power (MVA)	13.25	12.86	13.25	13.25
Real Power(MW)	13.25	12.86	13.25	13.25

From Table VI shows for Test System II connection, all Three Phases have the phase difference of 60° achieve on the transmission line division, While the phase voltage and the line voltages are same. To delta-Star delta-inverted Star connection and diametrical connection experience voltage increase to transmission division from 65kV to 159kV. Meanwhile, Star-Star Star- inverted Star connection also experienced voltage increase to 92kV. Voltage increase for transmission line influence by delta to Star connection and turns transformer ratio which are used. Then acquired 62.98Mwatt and 62.82Mwatt to delta- Star delta-inverted Star connection and diametrical connection. While for Star-Star Star-inverted Star only 36.32Mwatt. Voltage increase had stepped up power Six Phase System and obtainable delta-Star delta-inverted Star acquired 72.43%, diametrical connection form acquired 71.74% and Star-Star Star-inverted Star form only -0.656%. 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 has been selected to analyze 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 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 $X=0.1\text{pu}$. Transmission line distance is 16.19km and static is 1000Ω . Table VII show the theoretical result of Matlab Simulation for Test System III.

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TABLE VI The Results Of Six-Phase System For Test System II Using PSCAD/EMTD Simulation

Connections /Value	Delta-Star Inverted star	Star-Star Inverted Star	Diametrical
Generator Part			
I_{Phase} (A)	65.73	65.56	65.73
V_{Phase} (kV)	65.73	65.75	65.73
Apparent Power (MVA)	12.94	12.94	12.94
Real Power(MW)	12.97	12.84	12.94
Reactive Power (MVar)	0.3226	0.963	0.09437
Transmission Line			
Phase Angle (Degrees)	+58.74	+60	+60.32
V_{Phase} (kV)	159.8	92.33	159.23
V_{Line} (kV)	159.8	92.35	159.24
$P_{\text{Six-Phase}}$ (MW)	62.98	36.32	62.82
% of Power Increment(%)	72.43	-0.656	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-Star delta-inverted Star connection and diametrical connection experience voltage increase to transmission division from 12.66.kV to 131kV. Meanwhile, Star-Star Star-inverted Star connection also experienced voltage increase to 75kV. Then, acquired 10.01Mwatt and 9.811Mwatt to delta- Star delta-inverted Star connection and diametrical connection. While for Star-Star Star-inverted Star only 5.746Mwatt. Voltage increase had stepped up six phase power and obtainable form delta-Star, delta-inverted Star acquired 76.78%, diametrical connection acquired 73.74% and form Star-Star Star-inverted only -1.444%. 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-Star delta-inverted Star connection and diametrical connection which is exceed 73%.

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TABLE VII The Results Of Six-Phase System For Test System Iii Using PSCAD/EMTD Simulation

Connections /Value	Delta-Star Delta-Inverted star	Star-Star Star-Inverted Star	Diametrical
Generator Part			
I_{Phase} (A)	12.65	12.65	12.55
V_{Phase} (kV)	12.65	12.65	12.55
Angle(Radian)	0.003588	0.010722	0.003193
Apparent Power (MVA)	0.4808	0.4805	0.4714
Real Power(MW)	0.4808	0.4805	0.4714
Reactive Power (MVar)	0.001727	0.005184	0.001503
Transmission Line			
Phase Angle (Degrees)	+59.63	+59.11	+59.46
V_{Phase} (kV)	131.8	75.65	130.5
V_{Line} (kV)	131.8	75.65	130.5
$P_{\text{Six-Phase}}$ (MW)	10.02	5.747	9.813
% of Power Increment(%)	76.78	-1.444	73.74

Apart from that this study has proved that PSCAD/EMTDC software available for power analyses 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 three phase system. While on the transmission line division, calculation from simulation data need to be carried out to get power in transmission line.

V.CONCLUSION

Six Phase System is an alternative to replace the Double Circuit Three Phase Transmission line because of its advantage of enhancing the power transferring capacity by 73% within the existing right-of-Way. Simulation has been done for Double Circuit Three Phase model system and Six Phase system by using the softwares PSCAD/EMTDC and MATLAB. Increasing the number of phases will leads to reduction in gradient conductor surface voltage, spacing, corona effect, audible noise, television and radio interference and magnetic field giving scope to convert existing Three phase double circuit lines into Six phase lines. By using this software power transmission efficiency can be calculated. And also retrenchment in terms of cost can be calculated. This software gives accurate response based on the parameters given to analyses the circuit. With this lot many advantages a practical implementation of six phase transmission system must be given attention. This analysis act as a pioneer to design the six phase system by using the PSCAD/EMTDC and MATLAB software. As a developing country like India, demand for power supply will increase parallel with the development and exponentially with the industrial field.

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