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GIS-BASED IDENTIFICATION OF OVERLOADED DISTRIBUTION TRANSFORMERS & CALCULATION OF TECHNICAL ELECTRIC POWER LOSSES

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A B S T R A C T

This research was designed with the objectives to develop a standalone GIS application for electrical power distribution network companies having the capability of loss calculation as well as identification of overloaded transformers. For this purpose Hilal Road feeder in Faisalabad Electric Supply Company (FESCO) was selected as study area. An extensive GPS survey was conducted to identify each consumer, linking it to secondary pole of the transformer, geo-referencing equipments and documenting conductor sizes. To identify overloaded transformer, accumulative kilowatt hour (kWh) reading of consumer on transformer was compared with threshold kWh. Technical losses of 11kV power transformer and 220V lines were calculated using the data from substation and resistance of the network calculated from the geo-database. To automate the process a standalone GIS application was developed using ArcObjects with engineering analysis capabilities. The application uses GIS database developed for 11kV and 220V lines to display and query spatial data and present results in the form of graphs. The result shows that about 14% of technical loss on both high tension (HT) and low tension (LT) network while about 4 out of 15 general duty transformers were found overloaded. The study shows that GIS can be a very effective tool for distribution companies in management and planning of their distribution network.

1.0 Introduction

Pakistan Energy Sector is and has been for many years facing extreme crisis in energy deficit as a reason of which industrial and commercial activities has suffered a lot. This energy deficit is primarily due to insufficient power generation compared to increasing rate of consumption. A major portion of this deficit is also induced due to loss of power in transmission and distribution networks which unfortunately is aging and inadequate (PDIP, 2011). For a country like Pakistan where power generation projects have not been initialized, it is very important to decrease the loss of power in distribution and transmission network. Regrettably the distribution companies lack the use of efficient and modern equipment and techniques to control the power loss. These non-technical approaches also lead in theft and nonpayment by consumers. It has been already realized the role of modern technologies specially Geographical Information System (GIS) in planning daily operations (Datta, Verma, & Gupta, 1996).

The GIS provide a computerized tool for capturing, storing, analyzing and displaying spatial data. This technology can be used to efficiently map and monitor distribution network. GIS has been used in power distribution and utility business worldwide not only for mapping and monitoring but also to improve workforce quality in decision making (Chao, Qiang, Yuanlong, Su, Lihui, &Ludong, 2010). The major challenge that distribution companies face today is the monitoring of technical and non-technical losses in their network. There are many software solutions available commercially that uses engineering model to analyze distribution network. Nowadays some solutions have incorporated the use of spatial data in their analysis notable of which are ArcFM, MilsoftWindmil, ETAP, Synergee Electric and Bentley Electric. These solutions do not master in spatial data preparation yet, so data has to be exported to these software. Although distribution companies in Pakistan have tried to integrate commercial engineering models in their Planning and

Development (P&D) department but they are unable to utilize the benefits to full extent. It is need of the hour to provide them with an independent solution that can be used for data preparation as well as analysis. A standalone application with user friendly interface can be easily commissioned in the distribution companies. For this purpose ArcEngine provides a good platform for developing an application that can serve all requirements of distribution companies. Together with the power of programming languages and ArcObjects this application will have the power of spatial data preparation and analysis as well as engineering calculations.

The main objectives of this study are creation of Virtual Electric Distribution Network and development of geo-database and calculation of technical losses on 11kV power distribution line & Identification of overloaded transformers with respect to consumption and development of standalone desktop application for spatial decision support.

2.0 Study Area

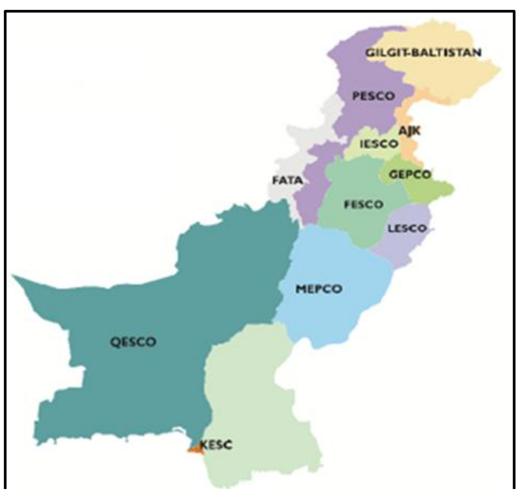


Figure 1: Geographical extent of distribution companies in Pakistan.

The study area selected for this research is one of the feeders from Faisalabad Electric Supply Company (FESCO). FESCO was established in 1998 and distributes electricity to 2.1 million customers. Geographical extend of FESCO shown in Fig.1. FESCO is administratively divided into four circles, two in Faisalabad, one in Sargodha and one in Jhang. These are further divided into 18 divisions and 106 subdivisions. According to Ferozie (2006), FESCO has about 10% to 13% distribution losses from about 635 feeders with a total length of about 51,418 km.

3.0 Methodology

3.1Data Acquisition & Preparation Phase

The first and the most important step in this research is the data acquisition phase which was completed by conducting GPS survey in the field. The main aims of the GPS survey were:

a) Identifying Line segments
b) Geo-referencing equipments like transformers, capacitors etc.
c) Taking consumer meter locations
d) Taking each pole GPS reading specially angle and intersection poles
e) Documenting attribute information and figures will be processed as images.

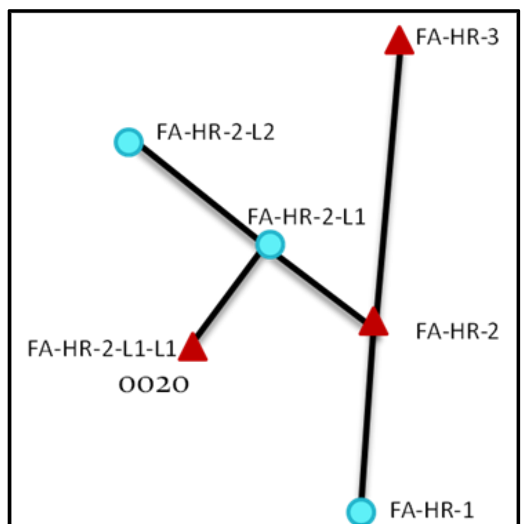


Figure 2: Pole and transformer naming convention for 11kV distribution network.

In the first phase 11kV primary line was mapped starting from the substation. The first reading was taken at the terminal pole which is the first pole from the substation and the 11kV feeder was followed from there. Pole and transformer naming convention were defined so that they are unique and can act as primary key in the database. Pole and transformers were also numbered in the field using irremovable markers. Polewas named by using the initials of substation and feeder for example the terminal is named FA-HR-1 where FA is the initial of factory area substation, HR is the initial of Hilal Road feeder and 1 represent the first pole from substation. Similarly the second pole is named FA-HR-2 and so on. In the Fig. 2, at 2nd pole, there is an intersection and the main 11kV line is divided into two. One part of line is moving in the right direction while the main line is moving straight. The poles on main line are named on a similar pattern while the first pole at the right of 2nd pole is named as FA-HR-2-R1 where R1 means first pole at right. Similarly if there is a left intersection at FA-HR-2-R1 then it is named as FA-HR-2-R1-L1.

Similarly the first transformer from substation was named 0010. First three digits in 0010 is the count of transformer while last digit 0 is an additional digit which may be used in future if new transformer is added between existing transformers for example if a new transformer is installed between transformer no 0020 and 0030, then it would be named as 0021. This nomenclature will give the independence of naming 9 new transformers and total of 999 transformers in one feeder. The mapping of secondary lines is performed after the completion of 11kV primary line mapping. Secondary line. Mapping is performed for all general duty transformers. At the time of secondary line survey, GPS reading of individual consumer is also taken. Each consumer is also linked to the secondary pole so that load can be allocated to sections of secondary line. Additional to pole and transformer number, phase and tariff of consumers is also written on a predesigned survey sheet. Table 1 shows the filled survey sheet of primary line mapping.

For consumer mapping the most important element is the identification of consumer account number in the field because it is the account number that is later linked with the account number in the master database of FESCO. In case account number is not found at site then meter number is taken and then later linked with master database.

Table 1: The filled survey sheet of primary line mapping

S-E	GPS No	Pole Number	Trans Size	Trans Number	Trans Use	Capacitor	Conductor	Int
S	29	FA-HR-71					Dog	
	30	FA-HR-72					Dog	
	31	FA-HR-73					Dog	
	32	FA-HR-74	100kVA	0340	General Duty		Dog	
	33	FA-HR-75					Dog	
	34	FA-HR-76	50kVA	0350	Dedicated		Dog	
E	35	FA-HR-77					Dog	
S	36	FA-HR-77					Rabit	
	37	FA-HR-78					Rabit	
E	38	FA-HR-79					Rabit	Y
S	39	FA-HR-79					Gopher	
	40	FA-HR-79-R1	200kVA	0360	General Duty		Gopher	
	41	FA-HR-79-R2					Gopher	
	42	FA-HR-79-R3					Gopher	
	43	FA-HR-79-R4					Gopher	
E	44	FA-HR-79-R5	200kVA	0370	Dedicated		Gopher	
S-E	GPS No	Pole Number	Trans Size	Trans Number	Trans Use	Capacitor	Conductor	Int
S	29	FA-HR-71					Dog	
	30	FA-HR-72					Dog	
	31	FA-HR-73					Dog	
	32	FA-HR-74	100kVA	0340	General Duty		Dog	

3.2Database Design & Development Phase

Geodatabase development is the second phase of this research which starts simultaneously with GPS surveying. The geodatabase containing point and polyline maps for the study area. It is a file structure developed by ESRI for ArcGIS 9.3 and later versions. It stores data as folders in file system. A file geodatabase was created in Arc Catalog with the name of FESCO. Inside file geodatabase a feature dataset is created with the name of substation which is Factory Area. A projection system UTN 43N is defined while creation of feature dataset. Inside feature dataset five feature classes are created with the name of feeder . To convert waypoints into feature classes a text file is created with waypoint number and XY coordinates. A separate text file for line segments is also created with similar information using the start end data from survey sheets. These text files are used in ArcMap to create XY event layer from where data is exported into feature classes (See Fig.3 and Fig.4). In the point feature class the attribute field "GPS_No" contains the waypoint number which is loaded from the text files. Initially only the GPS_No field has data loaded and the rest of the fields are null by default. The attribute table is joined with the excel spreadsheet with GPS no and all the data from spreadsheet is imported in the feature class attribute table using the function of "Field Calculator". This data contains certain errors which need to be edited before it can be used for analysis.

a) Topology errors: Topology errors are induced in the data at the time of processing. This type of error includes pole connectivity, pole to line connectivity etc. These errors are removed by deleting extra points and snapping lines with poles. Topology rules are also created to verify the data.
b) Positional errors: Some errors are induced in the data because of weak GPS signals. A good GPS accuracy is 2 to 3 meters but sometimes due to weak signals and less GPS satellite connectivity; the accuracy is 10 meters or even 18 meters. For this reason some points are processed far away from their original position and can be corrected using satellite imagery. Overlaying points and lines over satellite imagery can identify the points with positional errors which are relocated to its probable location.
c) Data entry errors: Small data entry errors can affect the results in the analysis step. Some type of data entry errors are wrong case, wrong transformer number entry, wrong pole number entry etc. SQL queries were applied to verify the data.

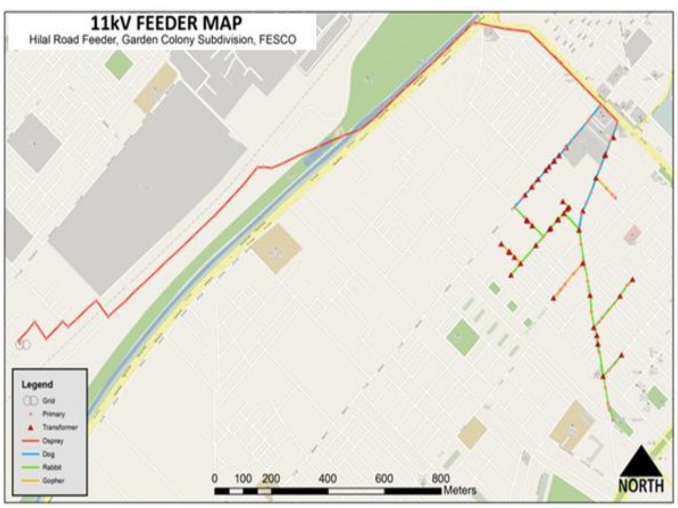


Figure 3: Hilal Road feeder primary network map.

Figure 4: Hilal Road feeder secondary network and consumer.

3.3Analysis Phase

The phenomenon of overloading can be detected using load flow models. A threshold value is defined based on transformer capacity, average load shedding time and power factor (PF). If the output power of transformer in a month exceeds the threshold power, the transformer is considered to overloaded and vice versa (Deaver&Radtke, 2011). The consumption history of each consumer is very useful in identifying the load on each transformer. This information is taken from computer database of FESCO and included in the geodatabase. The consumption reading is taken as kWh while transformer rating is done in Kilo volt amp (kVA) so it is very important to convert kilowatt-hour (kWh) into kVA. The kVA is always larger than the value of kWh. The ratio of KWh to kVA is PF. The PF is provided along with the transformer manufacturing specifications or it can be estimated. In this case PF is 0.95, then the conversion of kWh to kVA is performed. Then kWh is calculated from kW by multiplying it with number of hours the power was used. The number of hours can be calculated by obtaining data of load shedding hours from the subdivision office. Load shedding hours of the whole month is averaged to one day and subtracted from the 24 hours day. H = 24h – load shedding hours (lh). As meter readers in distribution companies take reading of each consumer after every 31 days, so to find total power usage hours the above equation is multiplied by 31 which is the energy consumption in kWh. The above equation defines the threshold used to identify the overloaded transformers. If consumption > kWh, then transformer = overloaded and Else transformer = normal. The amount of energy loss is the measure of distribution network's performance.

Table 2: FESCO database of consumer identified by account number with consumption history.

Account No	Meter No	Month										
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
2131150157410	43245	40	30	112	213	262	277	285	280	220	179	139
2131150155400	45355	63	61	66	53	96	94	121	120	115	89	91
2131150155300	6543	111	104	124	272	325	410	396	510	326	310	170
2131150153900	7543	68	63	70	52	62	150	180	90	40	52	70
2131150153500	6434	158	127	147	194	229	368	385	339	305	0	0
2131150153700	54346	12	26	34	32	39	43	70	70	55	40	39
2131150153800	76554	78	70	97	126	137	150	141	135	112	136	112
2131150151110	756754	21	16	40	43	82	248	163	186	83	70	70
2131150151120	98083	519	319	360	463	674	1,012	1,143	1,390	883	850	730

Table 3: Conductors used in distributions systems with their current carrying capacity and resistance.

Name	Ampacity	Ohms/km 25^C	Ohms/km 50^C
Gnat	147	1.0895	1.3049
Gopher	160	1.12501	1.3083
Ant	200	0.550	0.604
Rabbit	242	0.56047	0.7069
Wasp	315	0.2747	0.3017

In this study, a slightly different approach is adopted in which GIS data is used as a basses of loss calculation. Loss is calculated within a GIS tools by using mathematical engineering formulas embedded in the system. Power losses in a distribution network is a function of current and resistance of conductors used and can be defined by P = I2R. Where; I is current and R is resistance. According to above equations it can be concluded that that voltage and current is inversely proportional. That is why long transmission lines are high voltage lines to reduce the amount of current. In secondary lines, voltage has to be dropped to 220V and consequently current increases and loss becomes higher. Another technique used to control the amount of current is the installment of capacitor banks which stores electric charges.

Table.4: Maximum and minimum average current load (A) from January to December

Month	Avg. Max	Avg. Min	Average Load
Jan	95	27	61
Feb	115	40	78
Mar	118	44	81
Apr	129	71	100
May	132	82	107
Jun	159	99	129
July	168	104	136
Aug	159	99	129
Sep	142	91	117
Oct	132	72	102
Nov	94	38	66
Dec	89	31	60

3.4 Application Development Phase

In the final phase of this research a standalone GIS application was developed that has the capability of spatial data presentation and query as well as engineering analysis. The application was designed to present results of analysis in the form of graphs. All the algorithms developed for identification of overloaded transformers and calculation of technical losses was embedded in the application.

4.0 Result and Discussion

4.1 Feeder Statistics

As shown in Fig.5a, majority of transformers were 200-kVA which is about 33% of the total followed by 100-kVA which makes 19% of the total. 50-kVA and 25-kVA transformers each make 16% of the total and rest 1200-kVA, 630-kVA, 400-kVA, 15-kVA each makes less than 10% of total. One of the important element is loss calculation is the conductor size and length. Conductor sizes are standardized and given different names which are given in table 3. The conductor sizes used in 11kV Hilal Road feeder and length of each conductor are illustrated in Fig.5b.

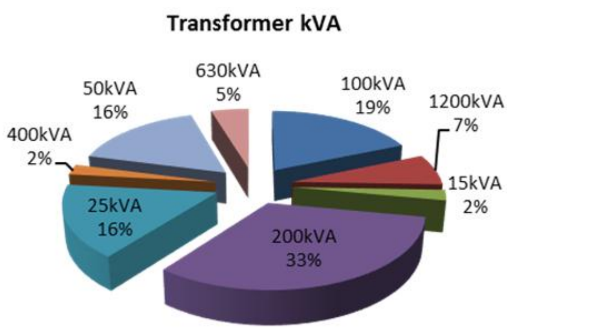


Figure 5 (a): Capacity of surveyed transformers and their percentage.

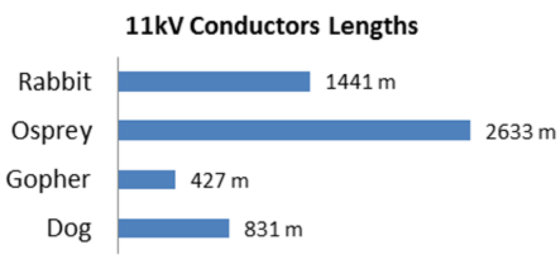


Figure 5 (b):. Conductors of Hilal Road feeder and their length.

4.2Overloaded Transformers

One of the important objectives of this study is to identify the overloaded transformers which are identified by the application and the results are presented as graphs. The accumulative consumption in kWh of all consumers in each general duty transformers is used to identify transformers which are overloaded in a particular month. The threshold kWh with consumption of all 100kVA general duty transformers in Hilal Road feeder illustrated in Fig.6.

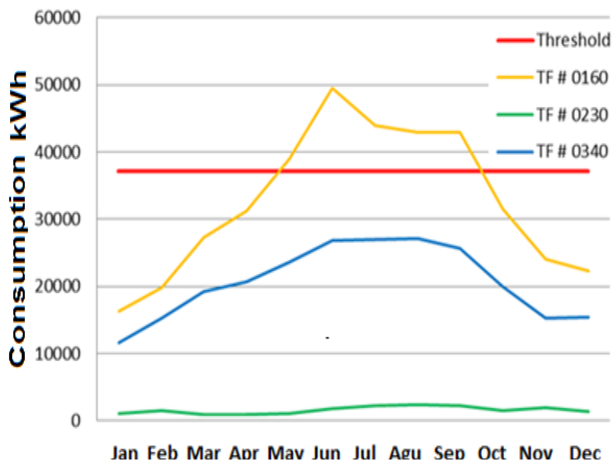
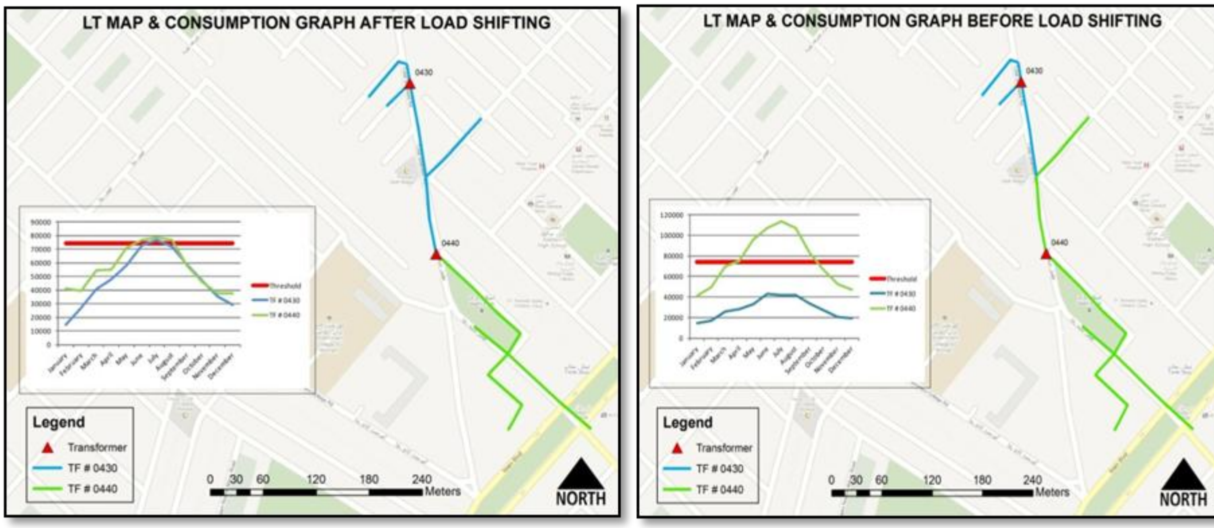


Figure 6: Threshold limit and consumption pattern of 100kVA transformers.

From the results of overloaded transformers, it is observed that five out of fifteen transformers in hilal road feeder are overloaded. The transformer 0440 is chosen as an example. As shown in Fig.7a, the transformer 0440 is overloaded and 0430 is not overloaded as depicted in a graph. Transformer 0440 has a comparatively larger low tension (LT) network then transformer 0430 and consequently greater number of consumers. Both of these transformers are spatially adjacent to each other. To eliminate overloading on transformer 0440, some of the load can be shifted to adjacent transformer 0430. The LT line of transformer 0440 is extending to the transformer pole of 0430 so load shifting can be done without installing any extra equipment. The LT line is disconnected at transformer pole of 0440 and connected at transformer pole of 0430 which shifts the entire load on that line segment to 0430. After modifying the database the algorithm was run again and new sets of results were generated. In new setting, the load on 0440 has decreased considerably while load on 0430 has increased making the load of both transformers within the threshold limit (see Fig.7b).



(a) **(b)**

Figure 7: LT network map and consumption graph of transformer number 0430 & 0440. a) Before load shifting. b) After load shifting.

4.3 Technical Losses

For the high tension (HT) losses the amount of current passing through the network is taken from the grid readings and value of resistance is calculated from the data surveyed. The Fig.8 illiterates the total losses on the HT network from January to December of 2010. It is evident that minimum losses occurs on January and gradually increasing so that the maximum occurs on July as the load on the feeder increases because of summer. From August to October there is a gradual decrease until it reaches lowest value of 16320-kWh in December.

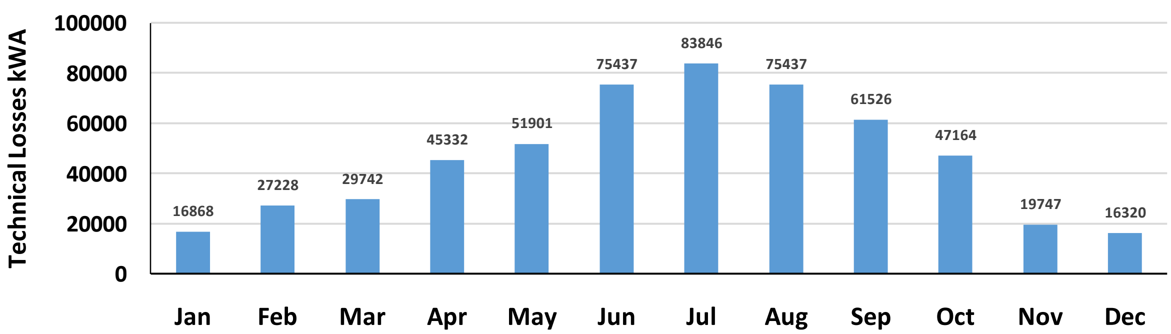


Figure 8: Monthly technical losses at 11kV line for the investigated year 2010.

5.0 Conclusion & Recommendations

This study successfully demonstrated the application of GIS in utility management companies especially power distribution companies to manage, monitor, maintenance and expansion of distribution network. GIS tools beside engineering methods can serve as energy management tools to save energy and preventing technical as well as non-technical losses. For a country like Pakistan where power generation projects have faced political interventions, the only way to decrease power shortages would be to decreases losses in distribution network. As far as this work provide GIS-based statistical framework for monitoring the transmission and distribution network, this line of research still can be further develop by developing online and real time monitoring system which will be more effective in power loss control and transformers overloading.

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