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Research Paper

ELECTRIC POWER GRID OPTIMIZATION FOR THE STATE OF SARAWAK AS AN EXAMPLE FOR DEVELOPING COUNTRIES

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The current worth of the power industry worldwide pegged at six trillion dollars. The cost of power plants are so high that only politicians of the highest level can make decisions on which to choose. The problem is that there are few engineers in the very top levels of politics worldwide and this is especially so in the developing countries. Incorrect political decisions with regard to facilities within the power grid can cause sufferings to the people of developing countries as debt creeps into their lives. This paper therefore aims to be a guide for politicians in developing countries to wisely choose the appropriate power plants unbiasedly. This is done by depicting the electric power decisions made in the state of Sarawak, Malaysia as well as of designs to further improve this grid. Sarawak has used some of the best minds in the world to develop a large and exemplary grid. Currently politicians in developing countries tend to get consultants from major corporations aboard. Every activity of large corporations must lead to maximum profit for themselves, often to detriment of the host developing country.

Keywords: Electric power grid optimization, Political decision making, Developing countries

INTRODUCTION

Engineers have tended to stay away from politics in both developing and developed countries. This problem was highlighted by many top thinkers and this cannot carry on as high technology becomes increasingly indispensable in developing countries. Experienced engineers need to be at the highest decision making levels of countries. This sphere is currently the realm of lawyers. In some countries like China, top engineers are just picked to be politicians but in a democracy engineers have to be cajoled to become politicians for the benefit of society (Duderstadt and James Derstadt, 2008).

In this work, the power system of Sarawak, Malaysia was studied and designs were formulated to optimize it further as a

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reference model for other developing countries.

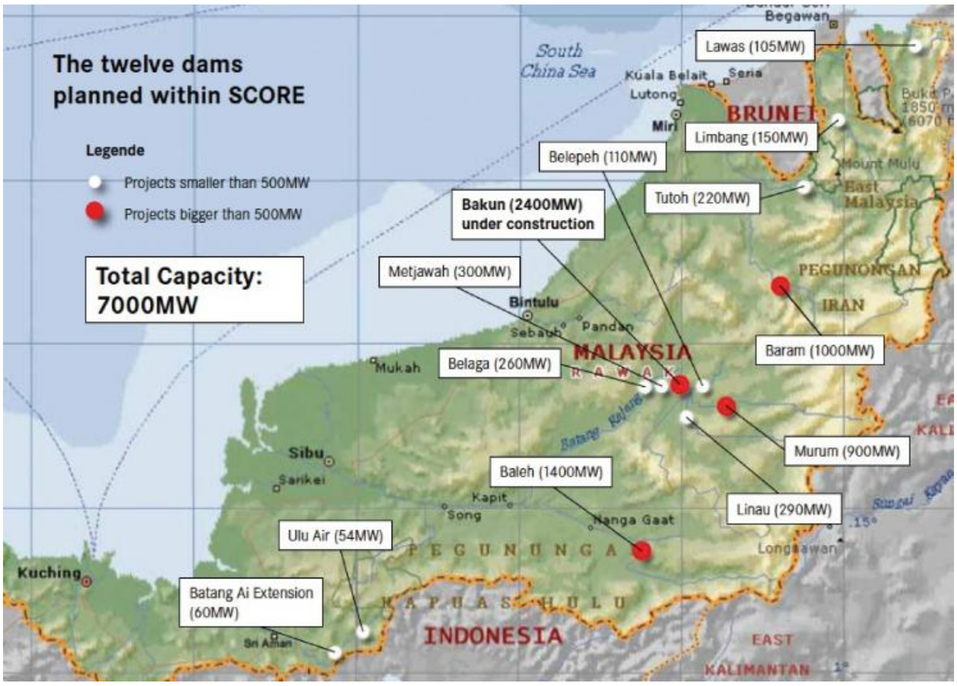
Sarawak is the largest state of Malaysia (at 124,450 km^2) but with a population of only 2.5 million. Sarawak is located on the equator and therefore has a rainfall of about 4000 mm (157 inches) per year. This compares to a USA average of 715 mm (28 inches). The topography is also of high mountain ranges at the border with Indonesia. This four factors of large land area, low population density, high rainfall and mountains ranges makes it ideal for hydroelectricity production. It is for this reason that Sarawak has already built three dams with two fully running and nine more in the planning stage. The sites of these dams are depicted in Figure 1.

Sarawak's hydroelectricity resources were confirmed the SAMA Consortium, under a technical aid to Malaysia granted by the German government via the German Agency for Technical Co-operation (GTZ). A total 155 dam sites were identified, each with a potential to generate more than 50 MW. This gives a capacity of approximately 80,000 MW. Sarawak needs to tap to this resource because it is her advantage.

However many of the dam sites are located too close to each other such that the development of one site will flood some others. Therefore only 51 of the 155 dam sites can be developed. Their combined hydroelectric generation potential is 20,000 MW (the current usage for Sarawak is 1,695 MW). Figure 2 shows the current grid system in Sarawak to carry the power from the power stations to the consumers.

In 2013, the amount of CO_2 emitted to the atmosphere was the highest in earth's history. The figure was 36 billion tons. As this keeps

Figure 1: The 12 New Dams Sites in Sarawak



up we will have more disasters like Sandy and the Japan tsunami. A scientist from U.N warned that a two degree rise in earth's temperature will trigger floods, droughts and storms (Garside Ben and Baird Jane, 2014). Human beings inevitably need industrial production, the choice for humans is use highly polluting coal fired plants or clean energy like hydroelectricity, wind or solar. If Sarawak fully utilizes all her hydroelectric potential, many of the heavy industries planned for construction in China can be moved to Sarawak thus taking out the huge increase of CO_2 emission from coal fired power stations of China. Industrial production needs lots of cheap energy, Japan enabled her huge spurt of industrial production after World War II (WWII) because of the large utilization of nuclear energy. The introduction of nuclear power in Japan after WWII was encouraged by USA in the hope that it will deter Japan from going into another war to secure resources. Nuclear power gave Japan cheap electricity to kick off her huge industrialization program (Jha Saurav, 2010). India hopes to get the same spurt with thorium based nuclear energy because of the abundance of thorium in India (Adee Sally, 2010). In fact Japan went through a phase of eliminating the dependence on nuclear power after the Fukushima disaster in March 2011, but has recently (2014) decided to embrace fully nuclear energy because this short experimentation with hydrocarbon energy was just too expensive and resulted is too much pollution. Besides the professor emeritus, Kiyoshi Kurokawa from the University of Tokyo concluded from the report of the Fukushima disaster investigation team, that it was not the tsunami but the lax safety protocol in the construction of the plant that caused the disaster (Orcutt Mike, 2014).

TECHNICAL CONTENT

In Sarawak the construction of the 13 dams planned or already built have a main purpose of powering the heavy industries near Bintulu which is gradually becoming the load center for Sarawak. The current load center is in the largest city and capital, Kuching.

Other renewables like wind and solar were tried out but failed to proof feasible. Solar power in Sarawak is a problem because though there is sunlight, it is quite often blocked by the heavy cloud cover, typical of equatorial areas. Also fungus grows very fast in an equatorial climate. This fungus even consumes the minerals within the solar panels rendering them opaque to the flow of sunlight to the photovoltaic cells (Noack-Schönmann Steffi, 2012).

The other option of wind will not work unless with proper calculation of the dimension of the wind turbine in accordance to the low wind speed value. There is a formula below should be used which gives the full dimension of the wind turbine given a specific average wind speed. The energy extracted from a wind turbine is given by:

$$E_k = ½ MV^2 \text{ where } M = °AV \text{ x } eff \quad ...(1)$$

where M = mass, ° = density, A = area, V = wind speed and eff = efficiency of the wind turbine. Assuming the wind is in a form of a cylinder of air. The theoretical maximum efficiency of a wind turbine is 16/27 or 59%,

$$E_{k\,max} = (½\ °AV^3)16/27 \quad ...(2)$$

This is Betz' law, however empirically the amount of energy extractable from a wind turbine ranges from 40 to 47% (Betz Albert, 1946). Notable from this equation is that the wind speed is the most important factor because it is cubed in the equation. But wind speed is very low in the equator where Sarawak is located. Sailors of old dreaded the equator because they could be stuck in these regions for months due to the lack of wind. Wind energy in the equator is possible only if specially designed wind turbines are used to cater for the low wind speeds. One wind turbine project in Sarawak where a wind turbine from a temperate country was just imported and planted (not considering the local low wind conditions) was a dismal failure.

Basically solar will work optimally deserts like Saudi Arabia, wind is for the North Sea countries like Norway. In equatorial Sarawak, hydroelectric dams is the best choice. Each country should find her advantage and fully utilize it and for Sarawak it is hydroelectricity. Also no power generator works as efficiently as a dam because it uses only one engine, the generator.

The one older dam in Sarawak, the Batang Ai has a relatively very low record of tripping and maintenance cost. The simple logic is that in a dam, the falling water replaces the complicated Gas Turbine (GT), the coal fired steam engine or and Internal Combustion Engine (ICE). Upon receiving a phone call from the power control center in Kuching, 300 MW of electricity from the Bakun dam can be loaded on the Sarawak grid within 30 seconds. This is compared to 45 minutes for a GT, an hour plus for an ICE, and eight hours for a coal power station.

Also the staff at the Batang Ai power stations do not face hazards of up to 103 dB(A) of sound pollution as in some parts of the ICE power stations. The Preventive Maintenance (PM) at the ICE stations are also hazardous. Huge pistons the size of a truck need to be taken out and placed in a container of kerosene to be scrubbed manually. The diesel and kerosene outgassing have a very negative impact on the staff. At the GT in Bintulu the high frequency noise attracts a four inch long insect called Emperor Cicada. The whole floor of the power station is littered with these dead insects. If it is cleared, the next day it will be full again. Apparently the high frequency noise the GT produces attracts the insects but they die once they reach the GT. If the power station noise can kill this insect, there must be some harm to humans. Statistically GT power station staff of Sarawak Energy Berhad (SEB) health is relatively bad. On the other hand, the hydroelectric power station staff has the best health statistics in SEB.

Another advantage of the Batang Ai dam is that it is normally used to balance out the inductive load in the grid when it is run as a synchronous motor to produce capacitive VArs. Note that it is very easy to disconnect the prime mover in a dam by just shutting the inlet water flow. In a GT power station, the gas turbine has to be separated from the generator via the contactless clutch which is much more difficult and often not possible. In contactless clutch there is engine oil between the GT and the generator instead of two plates clamping as in a car's clutch. The GT's shaft turns, resulting in a spin of the engine oil and this spinning oil turns the generator shaft. It also takes 45 minutes for the GT to startup or shutdown so it is not normally run as a synchronous motor to balance the inductive load of the grid. The difficulty of disengaging a prime mover from a generator in an ICE, GT or steam engine is the same reason they are the last choice to run as a synchronous motor to produce capacitive VArs to balance the mostly inductive VArs of industries (mostly induction motors).

Thus the majority of Sarawak's electric power is from hydroelectric dams. The other major source of electricity is coal power stations, GT and ICE. Table 1 depicts the power generation in Sarawak. Table 2 shows the forecast indicating an expansion of non-organic power demand specifically to supply the heavy industries currently being built in the central portion of Sarawak. Table 3 shows the current and power carried by the main power lines.

In gas turbines the input temperature of the burning gas and compressed air is 900-1400 °C and the output is 450-650 °C. This exhaust gas is hot enough to heat up water to produce

Table 1: Current Power Generation in Sarawak

Power generation in Sarawak						
				Capacity	**Running**	
Biawak (ICE, GT)				96	0	Spinning reserve 350MW
Bintulu (gas turbine)						
6 X 33MW GT,						
2X100MW GT						
1X115MW Combined Cycle				513	405	
Miri (gas turbine)				79	60	
Total gas =	592					
Sejingkat (coal power) Unit 1 & 2 = 50MW, 3 & 4= 55MW				210	200	
Mukah (coal power) capacity 2 X 135 MW				270	230	
Total coal =	480					
Batang Ai (hydro)				104	80	
Bakun (unit 3,4,5,6,7,8 at running=180MW capacity=300MW)				1800	720	
Total coal =	1904					
	Total hydro =		1904			
	Grand Total =			3072	1695	

Table 2: Power Demand Forecast in Sarawak

Demand in MW	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Organic load	991	1050	1113	1180	1251	1326	1406	1490	1580	1674	1775
% Contribution	92%	77%	58%	42%	36%	32%	33%	30%	32%	33%	34%
Energy intensive and export	90	307	807	1637	2217	2817	2817	3417	3417	3417	3417
Total load demand	8	23	42	58	64	68	67	70	68	67	66
Total Instaled capacity	1260	1850	3762	4570	4570	5170	5170	5720	6024	7024	7294
Reserve margin (%)	14%	27%	49%	38%	24%	20%	18%	14%	17%	28%	29%

Table 3: 275 kV Existing Power and Current Carrying Capacity

275 kV Transmission lines	MVA per circuit	Total MVA with two circuits	Total current carried by two circuits
Engkilili-Mambong	587	980	190
Mambong-Matang	587	980	110
Batang Ai-Engkilili	294	500	88
Engkilili-Kemantan	600	1020	113
Kemantan-Oya	600	1020	150
Oya-Selangau	587	998	480
Selangau-Kemenan	587	998	475
Kemenan-Bintulu	587	998	535
Bintulu-Similajau	587	998	210
Similajau-Miri	587	998	90

steam to run another generator. This is called a combined cycle or Rankine cycle. Basically a steam generator is a heat engine which works using the same logic as an air conditioner with four basic parts namely the condenser, the evaporator, the compressor and the expansion valve. The combine cycle (gas turbine and steam engine) generator in Bintulu produces 115 MW of electricity. The cooling of the condenser in the combined cycle is done with sea water.

A good example of grid improvement for literature review is the EriGrid Company on Ireland to link up Leinster and Munster. This project links to the line between Knockraha in Co. Cork to Great Island in Co. Wexford to Dunstown, near Kilcullen, in Co. Kildare to ensure high quality and reliable electricity supply for homes, farms and businesses in the southern and eastern regions. It brings about benefits such as:

- The grid line will helpto secure a future electricity supply for Leinster and Munster.
- Help to enable Ireland meets her 40% renewable electricity target as renewable energy is integrated into the grid, thereby reducing reliance on imported fossil fuels.
- Improving the current grid in the south and east of Ireland where the current supply is not sufficient.
- Providing a platform for job creation in the south and east of Ireland.
- The project will facilitate further electricity interconnection with the European grid (either Britain or France), providing a more secure and reliable electricity system.

The current Ireland national power system is an interconnected network of 400 kV transmission lines which connects Moneypoint power station in Co. Clare to Woodland substation in Co. Meath and Dunstown substation in Co. 220 kV and 110 kV lines are also used in the grid. The overall transmission line length is 6400 km.

Based on assessments report, it was determined that the optimum solution was to construct a 400 kV AC overhead line linking Cork and Kildare via Wexford to meet the needs for south and east.

These three connection point of Dustwon Sub, Knockraha Sub, and Great Island Sub were identify for this connection to enhance the 400 kV grid because they are geographically well-positioned to meet the condition of the network development. The Ireland Grid link project estimated to cost $836 million (EirGrid Plc, 2014).

Also in Europe, the International Electrotechnical Commission (IEC) did a research to determine how extensive usage of renewal energy can be done to prevent global warming and reduce dependence on imported fossil fuels. Their design envisages a connection of grid to as large as possible to cater to the unavailability of solar energy during a sudden cloud cover or unavailability of wind power during a sudden low wind situation. Large energy storage was also determined to be one of the solutions. Batteries with liquid electrodes have been suggested as a form of grid energy storage. Already the Synchronous Grid of Continental Europe which is also known as the Continental Synchronous grid is the largest electrical grid in the world. The whole grid is locked on a 50 Hz frequency serving over 400 million customers in 24 countries (International Electrotechnical Commission, 2012).

In the USA a large substation called the Tres Amigas is being built to interconnect the three large grids of the USA, the Western Interconnection, the Eastern Interconnection and the Electric Reliability Council of Texas (ERCOT) grid. Electricity from each grid is converted to DC and flows in a smaller DC High-Temperature Superconductor (HTS) wires in a 58 km^2 area where any of the three grids can pull out power or supply intermittent renewal energy from wind or solar farms. Superconductors have the ability to keep electrons flowing within it for long periods of time making them energy storage devices. The TresAmigas substation can initially handle 5 GW, expandable to 30 GW. HTS wires conduct electricity about 200 times better than copper wires of the same dimensions (Melhem, 2012).

Salim, Prashobh *et al.* researched the possibility of a solar and wind power for Borneo-wide power grid. This paper researched on possible of incorporation of solar and wind power farm for Sarawak power grid. With included potential location for solar and wind power generation in Sarawak. Simulations were made for the renewable energy integration into the existing power grid. It takes into account the problems encountered like synchronization and when faults occur. Research was also conducted on the current grid control system, Supervisory and Data Acquisition System (SCADA) to study if it is possible to replace it with a distributed internet based network. This network runs on Multi Protocol Label Switching (MPLS) topology and core and edge routers are connected with Local Area Networks (LAN) at points of generation and distribution connected by fiber optics cables to form a wide area communication network (Salim Maaji *et al.*, 2013).

The exploitable potential of hydroelectricity in Malaysia is 123 TWh per year. 70% of this lies in Sarawak, because of its abundant rainfall and topography. Sarawak has numerous rivers flowing down from steep mountain ranges at the border with Indonesia. Some of these ridges are of up to 1,200 meters high.

The first dam built in Sarawak was the Batang Ai dam. This is a relatively small dam completed in 1985 which produces 104 MW. The operation of the dam was so successful that the Sarawak government decided to build other dams.

The Batang Ai Dam is a concrete-face rock-fill dam in Batang Ai National Park in Sarawak. The power station comprises four 26 MW turbines which totals to an installed capacity of 104 MW. Construction of the dam started in 1982. The financing for the dam came from the Asian Development Bank. The construction caused a displacement of approximately 3,000 people from 26 longhouses. These people were moved into the Batang Ai Resettlement Scheme where they were trained to cultivate cocoa and rubber but this program was not successful. A mistake was made 1970s of providing each affected families quite a lump sum of money. The villagers, who never saw such a great sum of money, lavishly spent it all in futile expenditures. Some even bought Mercedes cars for use in jungle roads, thereby destroying it in a short time. Most of the villagers squandered all the money in a short time. Their minds were not ready or educated to use this money. The best approach to handle the villagers would have been to give them a “salary” for the rest for their lives.

The next dam which is the Bakun dam was built at a cost of $2.4 billion. Construction of the 2400 MW dam began in 1993 initially as a private concern but later taken over by the Ministry of Finance of Malaysia. The Bakun Dam is located on the Balui River, a tributary or source of the Rajang River. This dam is the second tallest concrete-faced rock filled dam in the world.

The 205 m Bakun dam has a reservoir area which is 228 m above sea level with an impounded reservoir of 695 km^2. The formation of the reservoir required resettling 10,000 people.

There are eight penstocks of 8.5m in diameter each with lengths of 760 m. 16 roller gates control the water flow. The operating water level ranges from a maximum 228 m and minimum 195 m. The gated spillway with concrete weir, chute and flip bucket has a capacity of 15,000 m^3/s. The gross storage volume is 43,800 million cubic meters. The powerhouse has a dimension of 250 m length x 48 m width × 48 m height. Each of the eight penstocks supply water to the Francis turbines of 300 MW which turns a 360 MVA air-cooled generator. This generator sends electricity to a 360 MVA transformer. Thus the total power supply output is 300 X 8 = 2400 MVA. The Bakun dam came online on 6th August 2011.

Bakun was originally justified on the basis of supplying electricity to peninsula Malaysia. 30% of the generated capacity was planned to be consumed in East Malaysia and the rest sent to Peninsular Malaysia. But this plan was scrapped due to the high expense of the undersea cable between Sarawak and peninsular Malaysia.

Currently the electric power from the dam is supplied to the grid whose consumers are increasingly the heavy industries located in the Samalaju Industrial Park. As of now there are four large factories where 275 KV lines goes directly into the factory substations. Planning is also going on to enable the Sarawak grid to supply the whole of Borneo island. This means supplying electricity to the other Malaysian state of Sabah, the Indonesian territory of Kalimantan and the country of Brunei. The optimum way to do this is via DC interconnections in-between grids. This way a fault in say the Indonesian territory will not affect the Sarawak grid (Maji *et al.*, 2013).

The next dam is the Murum dam, built at a cost of $1.25 billion. The dam is a Roller Compacted Concrete (RCC) dam of height of 145 m with an impounded reservoir of 245km². The dam uses four penstocks to turn 236 MW Francis turbine each, providing a total power output of 944 MW of electricity. The spillway is not gated. Sarawak Energy organized the dam construction with the main contractor being the Three Gorges Dam Company which built the largest dam in the world, the Three Gorges dam in China. The Murum dam is scheduled to supply power to the grid on June 2014.

In the construction of the dam, ash from burnt out coal from the Mukah coal power station was mixed with the concrete to make cement stronger. Actually this coal power station sold 42,000 tons of ash over the year 2011. The ash from the Mukah power station is stored in a silo to prevent dust pollution. From this silo, lorries carry it over a distance of 400 km to the Murum dam.

In the construction of the Murum dam 1555 people had to be resettled. The longhouse, the traditional home of the resettled people was constructed for them in the resettlement area. This longhouse was constructed on as a two story reinforced concrete frame sitting on stilts with hard wood floor. In each home there is a living room and three bedrooms. Each household within the longhouse is separated from each other by a brick wall and every third home is separated by a firewall. Other accessories provided are road, bridges, sanitation, drainage, water and power supply, community halls, chapels, kindergarten and garden plots. Each family was given 14 hecters of land. The displaced population has access to a forest reserve of 19,500 hecters.

The Mukah power plant is an intermediary power plant utilizing the low quality coal found in Mukah. It cost $306 million to build which is a much cheaper initial cost than any of the planned dams in Sarawak. To fire the two 135-megawatt (MW) steam turbines of the RM950-million Chinese-built Mukah plant, about 1.2 million to 1.4 million tons of coal are required a year generating 42,000 tons of ash a year. The coal reserves at the Mukah-Balingian Field can last for 50 years if the Mukah coal power plant is the only consumer. But another more efficient coal plant is currently being designed to be built in Balingian.

The next dam in planning stage is the Baram dam. This planned dam will use four sets of Francis turbine to generate 1,200 MW. The dam will be a roller compacted concrete type dam with a height of 185 m. Two saddle dams will be required to maintain full supply level within the reservoir. This dam will impound a reservoir of 388 km². An estimated 6,000 to 8,000 people from 32 longhouses will be directly affected by the Baram dam.

Sarawak needs the electricity that will be supplied by the Baram dam because demand for energy from energy intensive large factories located in Samalaju already exceeds current supply. The electricity from the Bakun and Murum (no output yet) dams has already been sold to energy intensive customers who have invested in Sarawak.

The development of the proposed Baram dam will also benefit the people of Baram as major roads are built to provide access to the dam sites. These roads will enable the communities in Baram areas to be more connected to the towns and therefore markets for their farm or jungle produce. By reorganizing these people in smaller resettlement areas there will be more synergy as they work together to transport their produce to the towns. Also there will be better access to education as schools are built for them. Access to town school and tertiary education is also more accessible. The option of moving to town jobs and businesses will also be opened for them. When finally built, at least 20,000 people from 25 longhouses will be displaced. The land compensation will depend on the needs of the directly affected communities to support their families at the resettlement area. The people affected by the dam will be compensated with homes, including longhouse, land, crops including fruit trees, graves, community halls and Churches. The final decision on the exact resettlement site will be agreed on by the directly affected communities themselves and the Government.

Proposed Improvements to the Sarawak Grid

This work ventures into how the Sarawak grid system can be improved. The weakest point in the Sarawak grid is the lack of lines carrying power into the current load center of Kuching city. Something needs to be done about the Kuching where most of Sarawak's population lives. Kuching does not have any significant power generation at sufficiently low cost. Strategically the load center should not be dependent on a power source a few hundred kilometres away.

In the current setup, Kuching depends on just two double circuits of 300 mm^2 wires bringing electricity into the city. These lines could be damaged by lightning strikes or sabotaged.

Figure 2: The Current Sarawak Grid

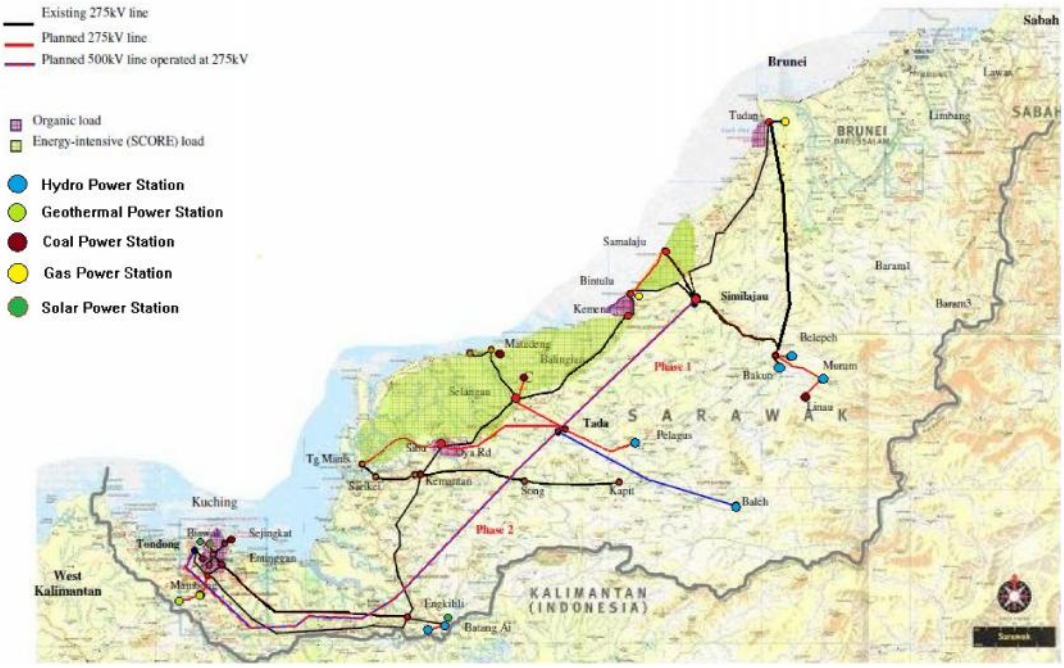


Figure 3: Single Line Diagram of Proposed Improvement to the Sarawak Grid

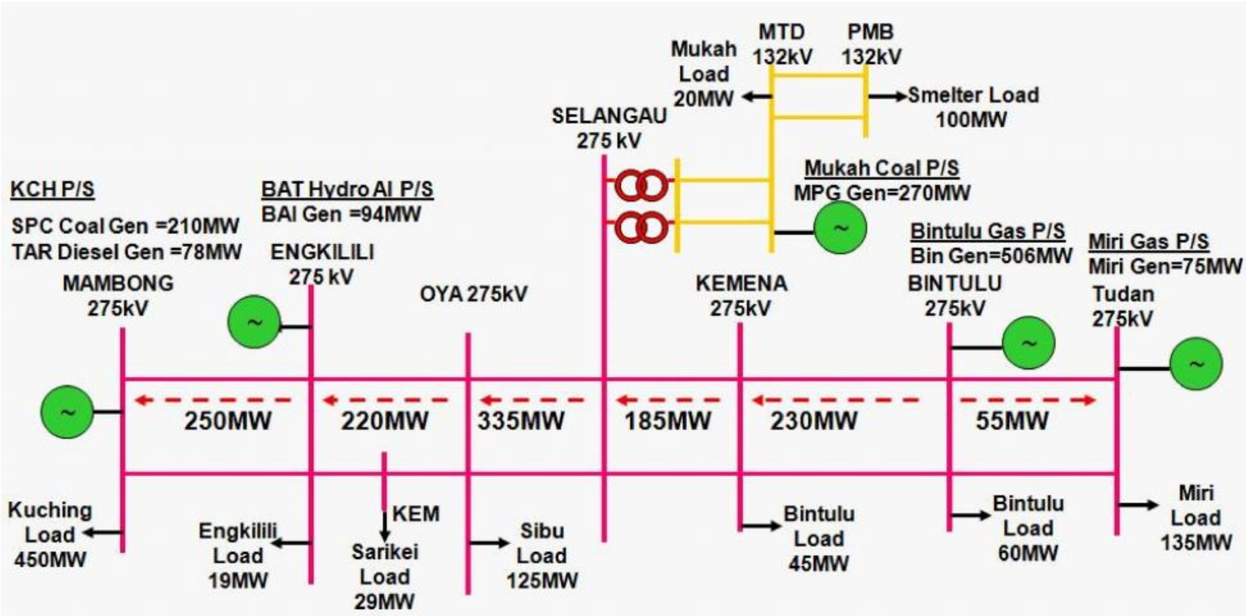
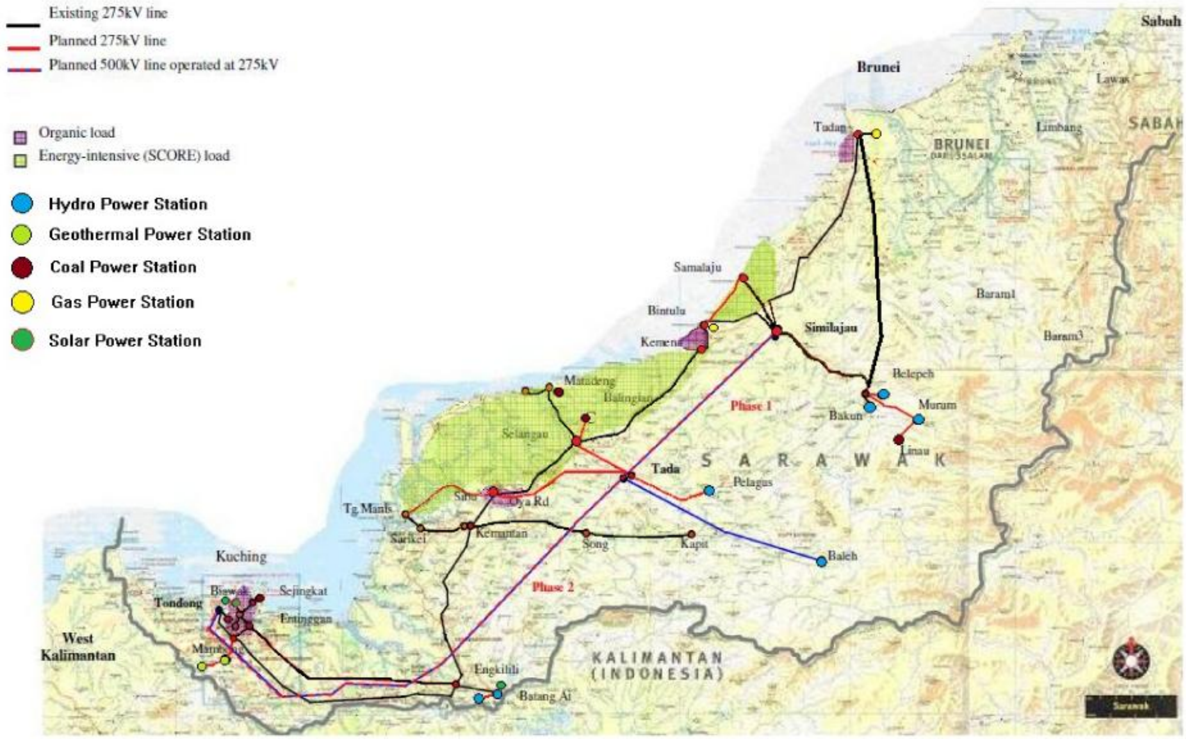


Figure 4: The Proposed Improved Sarawak Grid and New Power Source



The solution proposed in this paper is geothermal energy. 37 km south of Kuching is the Annah Rais Hot Spring where water surface temperature can reach up to 80 °C. This is above the surface temperature of the successful Salton Sea geothermal plants located near San Francisco whose surface water temperature ranges from 14-33 °C. Holes about two km are drilled below the Salton sea to access water at temperatures of 260 °C which is sufficient for geothermal electricity production. The existing coal power plant in Kuching has an inlet steam of 533 °C at a pressure of 7.62 Mpa to drive a 50 MW generator. The way to utilize a lower pressure steam is to use many smaller generators. The Salton Sea geothermal project uses 22 generators to produce 800 MW of electricity which is be more than the demand of Kuching city. And all this is renewal. In fact geothermal energy could potentially be a final solution to solve all the world's energy and global warming problem because no country that uses geothermal energy need to import any fuel. Below the ground anywhere on earth there is heat it is just a matter of how deep the geothermal well need to be. In earthquake regions where the larva is closer to the surface, the depth of the hole can be shallower (Adams Jeffrey, 2011; and Fridleifsson *et al.*, 2013).

Kuching currently has an ICE that generates 96 MW and a coal power station which generates 200 MW. The coal power station is expensive to run because the coal has to be ferried in from 450 km away in Kapit, Sarawak. Sometimes the coal is imported from Indonesia. Overall it cost MYR0.11 per kWh to run. The ICE uses gasoline and cost MYR0.22 per kWh to run. This is expensive considering the average charge per kWh is around MYR0.35. Currently the ICE is on standby unless there is a power trip of the whole grid. For ICE and coal power plants, size is important in the cost of the plant. The larger plant sizes benefit from economies of scale and efficiency.

Figure 5: Current Sarawak Grid

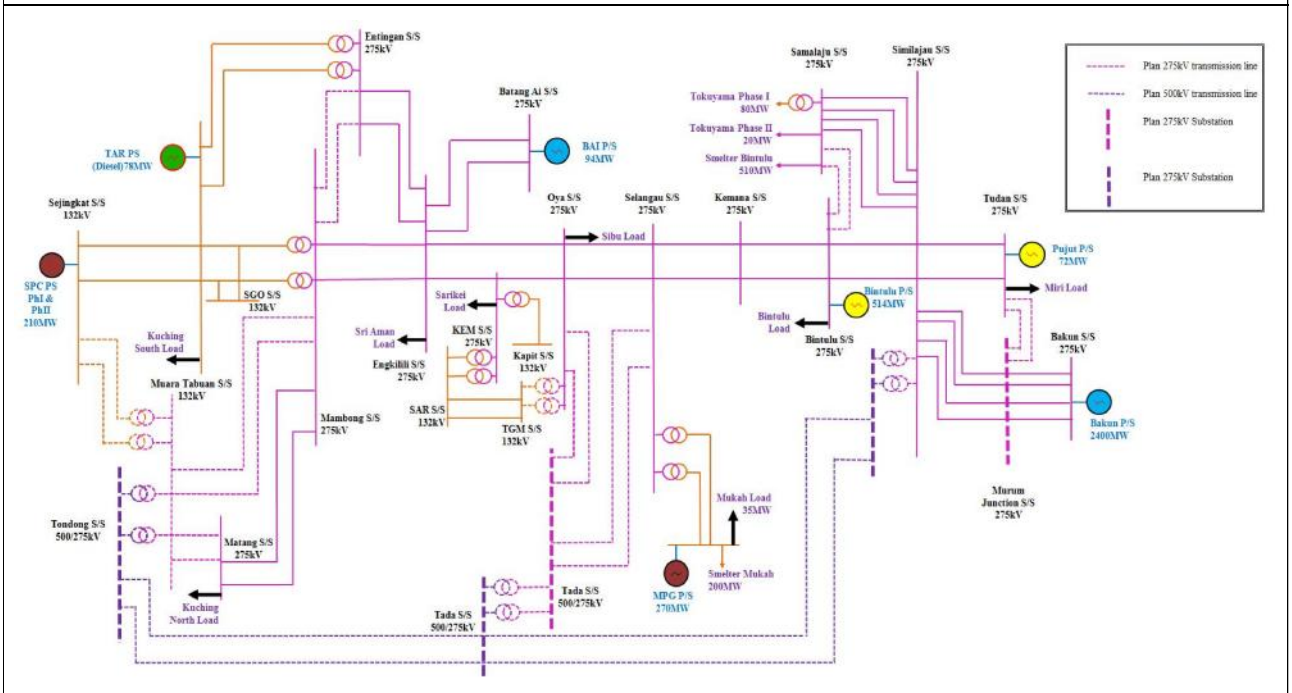


Figure 6: Proposed Improved Grid Inclusive of New Power Stations

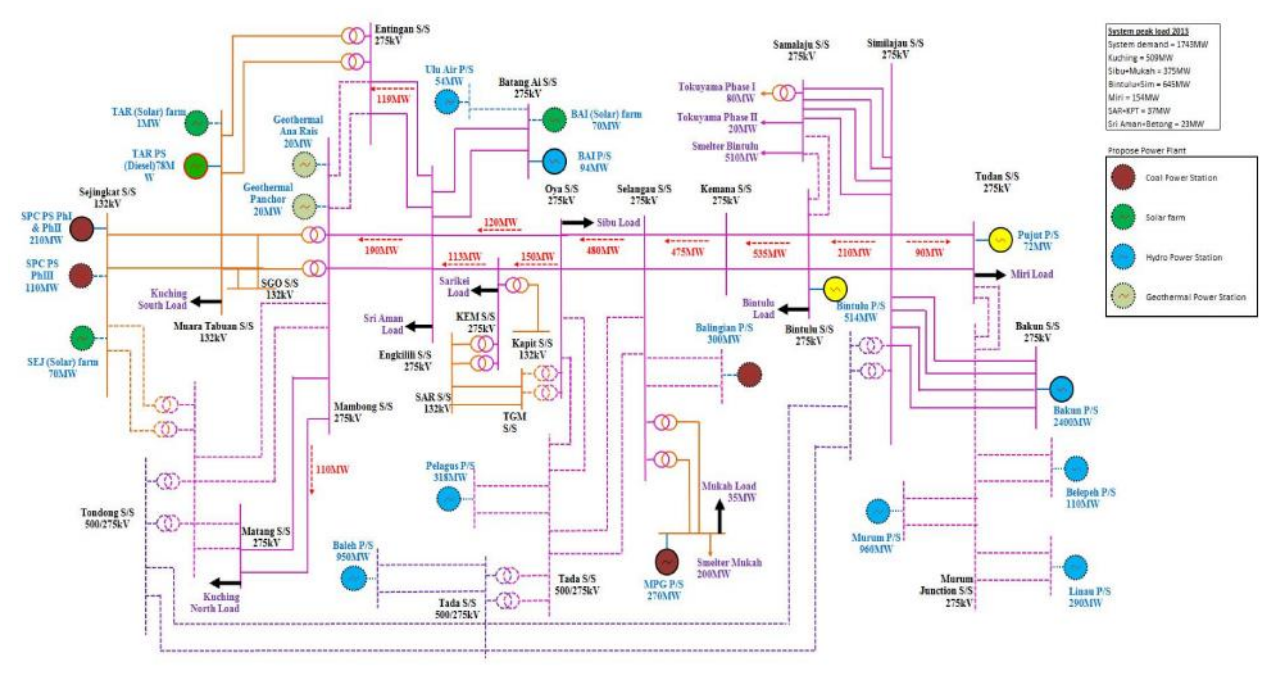


Table 4: Proposed New Transmission Lines

Transmission Lines	Distance (Km)
Tondong – SPC (132kV)	42
Entingan-Mambong (275kV)	36
Mambong-Tondong (275kV)	30
Tondong-Matang (275kV)	29
Tondong-Tada (500/275kV)	313
Tada-Similajau (500/275kV)	192
Tada-Oya (275kV)	30
Tada-Selangau (275kV)	50
Oya-Tanjung Manis (132kV)	40
Bintulu-Samalaju (275kV)	18
Tudan-Murum junction (275kV)	85

Other proposed improvement is the installation of solar farms in the existing ICE power station named TAR, the existing Coal power station named SEJ and in the hydro power station named BAI. This is now possible because solar panel manufacturing in China has driven down it's cost world-wide drastically.

The second improvement is of course running more lines from the cheap power centers to the load centers which are Kuching, Samalaju, Miri, Sibu and Bintulu. Figure 1 shows the existing grid and Figure 2 is the improvement proposed in this paper.

The Sarawak grid needs to be reinforced by adding new transmission lines to create a ring network around Sarawak. The current grid is not a ring and therefore any fault can bring the whole grid down.

The improved designed optimum grid for Sarawak is shown in Figure 3 single line diagram. The reinforcements that are needed are adding a 500 kV line starting at Bintulu to the Similajau substation (sub) double circuits which is connected to Tada (Sibu) new sub and stop at Tondong (Kuching) new sub. From the Tondong sub the 500 kV will be stepped down to 275 kV and link back to Mambong 275 kV sub and Matang 275 kV sub. At Tondong sub a further step down from 275 kV to 132 kV will be done and linked to SPC sub. At the Tada sub the 500 kV will be stepped down to 275 kV and link back to Selangau 275 kV sub and Oya 275 kV sub. The four subs that need reinforcement are Entingan 275 kV sub to Mambong 275 kV sub. This will link up the MAM-ENT-ENG, Tudan 275 kV link to Murum Junction 275 kV sub to make up a ring circuit of TUD-MJU-SIM. At the Oya 275 kV sub a step down to 132 kV will be done before connecting to Tanjung Manis 132 kV sub. This will link up OYA-KEM-SAR-TGM. The Bintulu 275 kV will be connected to Samalaju 275 kV to link up BIN-SIM-SJU.

The transmission lines that urgently need to be reinforced are the OYA-SLG, SLG-KMN and KMN-BIN where the current loading is over 50% of the line rating during normal operation. This is because there is a lack of power generation capacity in the southern portion of Sarawak and Sibu.

As Sarawak utilizes as much as possible of her renewal hydroelectric potential she will attract heavy industries worldwide to site their plants in this state. Big international companies are increasingly being pressed to source their power away from coal. So it is a win-win situation from all. Improving the grid to help carry all this power is critical in ensuring reliability of the whole system.

Another proposed improvement is to use new technologies. One idea is to use LEAP engines. Basically the exhaust coming out of a GT is hot enough to melt even the housing material. So to solve this problem, high pressure air from the compressor is blown into holes of the housing to cool it down. On the other hand in the LEAP engine the housing is made of ceramic which can withstand the high temperature of the exhaust. Thus the compressed air need not be wasted to cool the GT housing and can be utilized to produce more energy in the turbine. LEAP engines are currently being implemented in jet planes so a Purchase Requisition (PR) to General Electric (GE) is all it takes to build a LEAP engine GT for power production (General Electric, 2014).

Another idea is the promotion of the use of electric cars. With everyone using Electric Cars (EV), these cars will be most of the time be plugged into the grid. Because people normally drive to work for 20-60 minutes and park the car for at least the next eight hours. They then take another drive home and plug it in for another eight to ten hours. For the full utilization of EV there must be power sockets at all car parks such as is already done in Scandinavian countries and in the USA states such as South Dakota, North Dakota and Minnesota. In these places the power at car parks is to heat up engines so that they can start in the cold winters. With cars plugged into the grid most of the day, they can be a backup storage from which to pull electricity from. This will be needed in case of a sudden cloud cover over solar panels, a sudden atmospheric wind speed reduction which impacts wind farms or a sudden mechanical problem which brings down an ICE, GT or hydroelectric generator. Of course an improvement which needs to be made to the current Scandinavian car park plug points is to install meters on them to measure electric flow to and from the EVs.

All these development will provide a lot of power supply to the state of Sarawak. The Sarawak government has two options to use this power. One is to send it over the rest of

Malaysia via a High Voltage Direct Current (HVDC) cable of 670 km to the nearest point in the state of Johor, Malaysia. The second option is to attract huge heavy industries to come over to Sarawak. The first option is bogged down by problems because 670 km of undersea 300 mm^2 HVDC will cost almost that of a new Bakun Dam. Such a long undersea cable has also not been installed anywhere in the world. The energy loss in an undersea cable with it's much higher capacitance could be too high to be viable. Power loss is increased dramatically with amount of XLPE (cross linked polyethylene) insulation used around the conductor. The capacitance in an underground cable is depicted in Figure 3 and Equation (1) for single phase and Figure 4 and Equation (2) for three phase (Eteruddin *et al.*, 2012).

$$C = \frac{2®£l}{\ln\left(\frac{r_i}{r_c}\right)} \, Farad \qquad ...(3)$$

Figure 7: Cross Section of a Single Phase Cable Indicating Radius Used in Capacitance Calculation

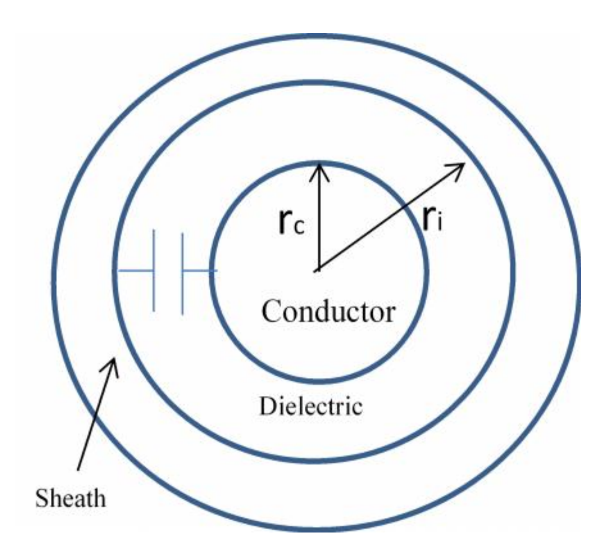
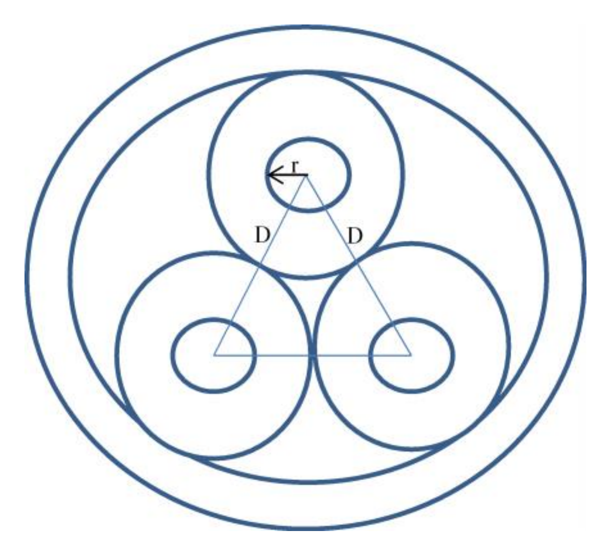


Figure 8: Cross Section of a Three Phase Cable Indicating Radius Used in Capacitance Calculation



$$C = \frac{2®£l}{\ln\left(\frac{D}{r_c}\right)} \, Farad \qquad ...(4)$$

With the construction of the new 500 kV backbone transmission line, there will be back-up to the current 275 kV grid. So if one fails the other takes over. Also there is much greater carrying capacity to move electricity all around Sarawak. The latest protection systems should be implemented in the substations. Previously with one 275 kV grid across Sarawak, there was a great difficulty in implementing the latest systems to help enhance power reliability because parts or the entire grid had to be shutdown to install the latest protection relays. With a 500 kV backup, upgrades can be continuously be implemented as they are developed by the big four in the power industry namely GE, Siemens, ABB and Schneider.

There is also a need to more efficiently manage the grid. The current SCADA Ethernet system from Harris Computers, USA is too slow to respond to fault triggered, even though signals are currently carried over fiber optic lines. An Internet Protocol suite (TCP/IP) based system will enable much faster respond time. Currently many power corporations are concerned about sending data over the internet because hackers may eventually control the grid. But the current Ethernet can as easily be hacked so that concerned is unjustified. Virus protection from established anti virus companies like McAfee can be contracted to secure the grid from hackers. The system should be automated as far as possible. For example if one generator in Bakun fails, taking off 300 MW from the grid, a specified low priority load should be automatically shedded immediately to safeguard the rest of the grid.

CONCLUSION

With all the improvement done on grid and power source in Sarawak, it will boost up developments in Sarawak particularly the mega power consumers in the Samalaju area, thereby providing a solution to the extensive pollution in China caused by coal power plants. The optimum grid and power sources will provide international investors highly reliable, efficient, economical and sustainable electric supply. It should be noted that Nikola Tesla who initiated the AC system used worldwide, started his system with hydroelectric energy generated at the Niagara Falls. This is what Sarawak is pursuing. Tesla made a statement that the world was not ready for his inventions but one day it will be used. That prediction is proving correct as the worldwide system is AC and his invention, the induction motor is driving the world's industry today.

A big political change has to happen to ensure mankind move away from ICE vehicles to electric vehicles which will be both a user of electric power as well as a perfect storage to take out power from, in case of an unplanned interruption in power supply.

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